FINAL REPORT ON UGC FUNDED PROJECT (MRP)

Name of the Project: Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam

File No: 41-983/2012 (SR) dated 26/08/2015

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ज्ञान-विज्ञान विमुक्तये

Annexure -VIII

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002.

Final Report of the work done on the Major Research Project.
(Report to be submitted within 6 weeks after completion of each year)

1. Project report No. 1st /2nd /3rd /Final Final
2. UGC Reference No. 41-983/2012 (SR) & 25.07.2012
3. Period of report: from 26.11.2015 to 31.03.2016
4. Title of research project *Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam*
5. (a) Name of the Principal Investigator Dr. Partha Pratim Dutta

   (b)Deptt. Mechanical Engineering

   (c) University/College where work has progressed Tezpur University

6. Effective date of starting of the project 03.12.2012
7. Grant approved and expenditure incurred during the period of the report:

a. Total amount approved Rs. 13,07,800/-

b. Total expenditure Rs. 12,62,036/-

c. Report of the work done: (Please attach a separate sheet): Attachment: I

(i) Brief objectives of the project:

- Surveying and samples collection of different species of woody biomass available in Assam, prominently in nearby tea processing industries.
- After characterization feed stock, different species of woody biomass had been gasified in a 10 $kW_{thermal}$ downdraft gasifier.
- The gasification efficiency was evaluated by measuring calorific value of producer gas generated from woody biomass with gas chromatograph. Experimental demonstration of locally available woody biomass gasification characteristics and recommendation of biomass gasifier for partial substitution of thermal energy in tea processing industries.

(ii)Work done so far, results achieved, and publications, if any, resulting from the work (Give details of the papers and names of the journals in which it has been published or accepted for publication: Reprints of papers are attached.

Objective-a Methodology: Survey work for biomass sample collection and present thermal energy sources used in different Tea Estates in Upper Assam like Warren Tea Limited (Figure6), Dibrugarh, Williamson Magor, Dibrugarh, Barooah Tea Estate, Jorhat, TRA, Jorhat, Williamson Magor, North Bank of Assam had been completed successfully.

Objective-b Methodology: The different collected biomass feedstocks were characterized by evaluating CHN and its calorific values for determination of gasification efficiency of downdraft gasifier. The different gasification feed stocks are presented as follows.

Woody biomass samples and their characterization

Selection and description of biomass samples

Ten locally available biomass samples had been considered for characterization. The brief descriptions of these biomass plants are presented below (Fig.1a to Fig1j).

1. *Psidium guajava*- It is an evergreen shrub, small tree native to the Caribbean, Central America, South America and India. It is widely cultivated in tropical and subtropical regions around the world. This tree is generally (2.7- 6.0) m in height, with wide-spreading branches and square. The wood of *Psidium guajava* may be used to make pole, fencepost, hand tools' handle, handicraft, charcoal and fire wood production. The average life of this plant is (30 to 40) years. The fruits of the tree are used for preparation of jam and jelly.

2. *Bambusa tulda*- This plant is found in the South-East Asian rainforest. It grows as undergrowth scattered or in patches. *Bambusa tulda* may grow anywhere between (12 – 24) m height. It has multifaceted uses including fuel wood, different handicraft material, fencing, erection of shed particularly in village, paper making industries, etc. The bamboo is a fast-growing plant, matures normally within 3 to 4 years. However, life of bamboo may be as high as 25 to 40 years and it dies after profound flowering.

3. *Camellia sinensis*- An evergreen bushy plant. The young leaf of this plant is used for production of different tea. It is prominently grown in Assam, India. As a plantation woody plant in tea estate, its average height is (1.0- 1.5) m. The productive average life of *Camellia sinensis* is about 50 years. Since tea estates in Assam generate biomass in the form of uprooted tea branches, pruning litter and branches of shading trees, etc., the uprooting is done at certain intervals of plantation to replant and to maintain optimum level of tea productivity. Such uprooted tea branches are generally used as cooking fuel through direct combustion in low efficiency traditional cook stoves. The introduction of improved cook stoves with higher conversion efficiency may lead to a substantial saving of uprooted biomass and this saved biomass may be used for tea manufacturing process heat generation. It has multifaceted uses including fuel wood, and structural material for decorative furniture making. The present gasification study is also considering the uprooted tea shrubs as a feedstock for gasifier.

4. *Samanea saman*- It is generally used as shading trees in tea estates. This is a tropical tree, grows (25-35) m, with rough wrinkled bark. The average life of *Samanea saman* is about 80 to 100 years. Average growth rate is 1.0 m per year and timber yield of a five years old plant is 10 to 25 $m^3 ha^{-1} y^{-1}$.

5. *Moringa oleifera* – The tree is slender, with drooping branches that grows to approximately 10 m in height. It is native to the southern foothills of the Himalayas in north-western India and widely cultivated in tropical and sub-tropical areas. It is also known as drumstick tree, and the fruits (drumstick) are consumed as vegetable. The average life span of this plant varies between 30 to 40 years.

6. *Polyalthia longifolia* –The tree may grow over 09 to 12 m in height. Found natively in India and Sri Lanka. It is introduced in gardens in many tropical countries. Its bark and trunk are used to manufacture fibre. Timber is used to make pencil, boxes and long masts. The average

maturity age of the tree is around 10 to 15 years.

7. *Delonix regia* – It usually grows to a modest height of mostly 10 m and can reach a maximum height of 20 m. It spreads widely and its dense foliage provides full shade. It is a fast-growing tree and mostly used for fire wood and sometime planks are used for supporting reinforced concrete slab casting. About 07 to 10 years, this plant becomes matured and red colour flowers come out.

8. *Azadirachta indica*- It is native to India and the Indian subcontinent including Nepal, Pakistan, Bangladesh and Sri Lanka. It grows in tropical and semi-tropical regions. A fast-growing tree can reach a height of (15–20) m and rarely grows to (35–40) m. Its maximum life may be as high as 200 years. This plant's oil is used for preparation of soap, etc. Generally matured branches are used for fire wood in rural areas.

9. Ficus lepidosa- It is a deciduous tree and grows to heights up to 6 m. It is widespread in tropical and subtropical areas. Its seed has white latex and trunk and branches are mostly used for fire wood in rural area. It becomes mature around 10 to 15 years.

10. *Dalbergia sissoo* – It is primarily found growing along riverbanks with 900 m elevation, but may naturally grow up to 1,300 m above sea level. The height of the tree is (10-20) m. This plant gives premier timber for shade and shelter. It is an excellent fuel wood. As a fuel wood, it grows in 10 to 15 years' rotation. The charcoal produced from this wood is excellent. Moreover, the timber obtained from matured plant is used for different furniture making and building fittings.

Therefore, ten locally available woody plants have been briefly described above. *Camellia sinensis* plant is a plantation shrub in tea estate. Uprooted tea shrubs have been proposed for gasification studies in a downdraft gasifier. Gasification performance of *Camellia sinensis* shrub is not found in literature for process heat generation. Even though *Camellia sinensis* is not fast growing for woody biomass production compared to other discussed woody plant. Its specific selection for gasification is that the plant is directly related with tea manufacturing industries for which the investigation is made.

Fuel samples considered

Nine woody and one non-woody biomass samples grown nearby tea estates of Tezpur University (latitude 26° 42′ 03″ N and longitude 92° 49′ 49″ E) as well as nearby other tea estates in east Assam (India) were collected for analysis of calorific value and CHN / O fractions. Three samples of each biomass were dried to moisture of 15 % (w.b.) that followed with pulverization by grinding machine. The ground mixture was finally sieved to 500 μm and oversized particles were removed. Proximate analyses of these biomass samples were performed to estimate the following parameters namely moisture content (ASTM D317373), volatile matter (ASTM D3175-73) and ash content (ASTM D3174-73). Similarly, ultimate analysis of feedstock was performed as per (ASTM E-777) for carbon and hydrogen, (ASTM E-778) for nitrogen and oxygen by difference [1].

Figure1a. Psidium guajava

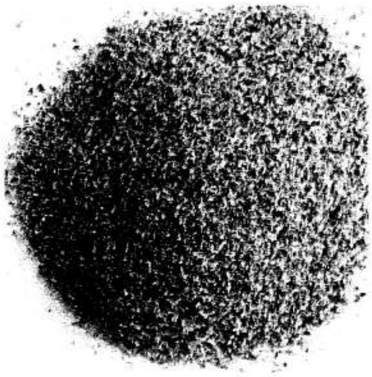

Figure1b. Bambusa Tulda

Figure1c. Camellia sinensis

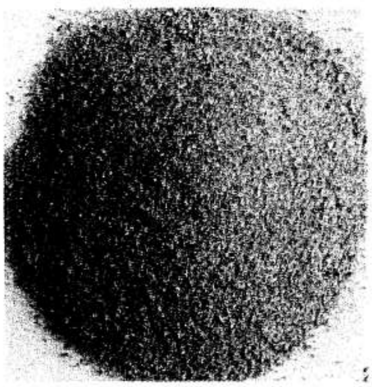

Figure1d. Samanea saman

Figure1e. Moringa oleifera

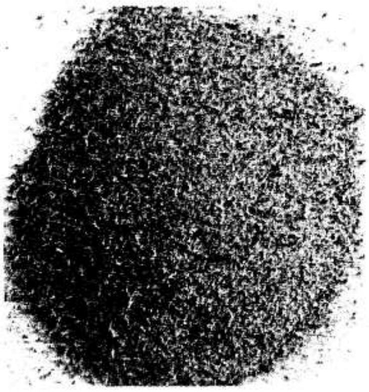

Figure1f. Polyalthia longifolia

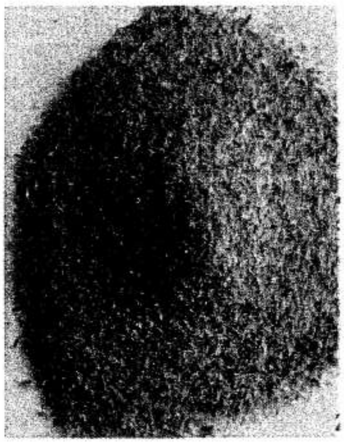

Figure1g. Delonix regia

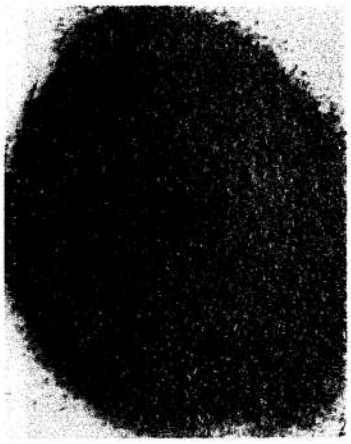

Figure1h. Azadirachta indica

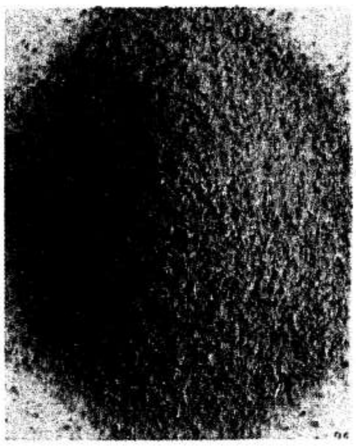

Figure 1i. Ficus lepidosa

Figure1j. Dalbargia sissoo

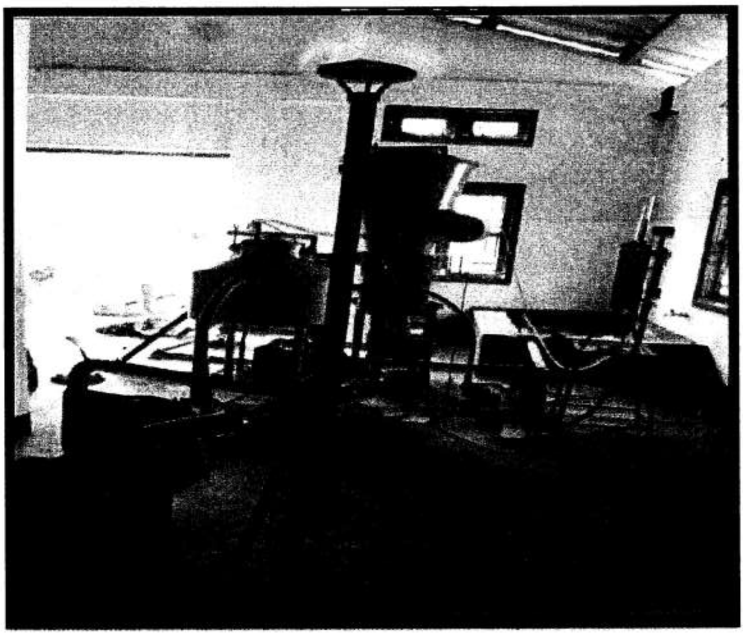

Figure 2. Biomass gasifier experimental setup

Experimental set up and instrumentation for measurement of calorific value and CHN/O analysis

The Figure 2 shows an experimental 10 $kW_{thermal}$ woody biomass gasifier. The ten mentioned biomass samples had been characterized by using a CHN Analyser (PerkinElmer, Series II, CHNS/O Analyser, 2400, USA, Figure 3). The higher heating value of biomass, (HHV), also called gross calorific value (GCV), has been determined by the oxygen bomb calorimeter (Make: 5E-1AC/ML, Changsha Kaiyuan Instruments Co., LTD, China, Figure 4). Both the instruments are available at Tezpur University, SAIC (Sophisticated Analytical Instrumentation Centre).

Gasification of ten biomass samples and producer gas calorific values determination

The downdraft gasifier (Make: Ankur, India) was operated according to the standard procedure prescribed by the MNRE [20]. Since the producer gas generator converts the solid biomass into gaseous fuel by series of thermo-chemical reactions, therefore to initiate proper gasification, some minimum warm up period is necessary. The hopper of the gasifier was fully loaded with biomass through top lid and then the lid was closed securely to stop entering excess air. A firing torch wrapped with cotton waste in support of kerosene oil was used to fire the gasifier through two air nozzles. The suction blower was started immediately and combustion air was controlled by means of the flap valve opening of the centrifugal blower such that oxidation zone inside the gasifier could be established. At the beginning, white opaque smoke was released that was not combustible. After about (15-20) minutes, the producer gas was less opaque with more combustible and continued with sustained flame in producer gas burner (flaring).

Junker gas calorimeter (INSURF, Make: Instrumentation and Refrigeration of India) was used for online measurement of calorific value of producer gas [21]. Producer gas contains five principal components namely nitrogen, carbon dioxide, some hydrogen, carbon mono oxide, and traces of methane out of which last three gases are combustible. Producer gas calorific value was measured by tapping a small amount of gas from the main gas stream to feed Junker gas calorimeter and then its calorific value was evaluated at an interval of 10 minutes. Two rotameters (Range: (0.1-10) m^3h^{-1}) were used to measure gasification air coming through air nozzles. The measurement of gasification air for different biomass samples is useful to estimate air-fuel equivalence ratio for gasification. The best operating point of the gasifier for a particular fuel may be determined by measuring the producer gas calorific value and corresponding air-fuel equivalence ratio.

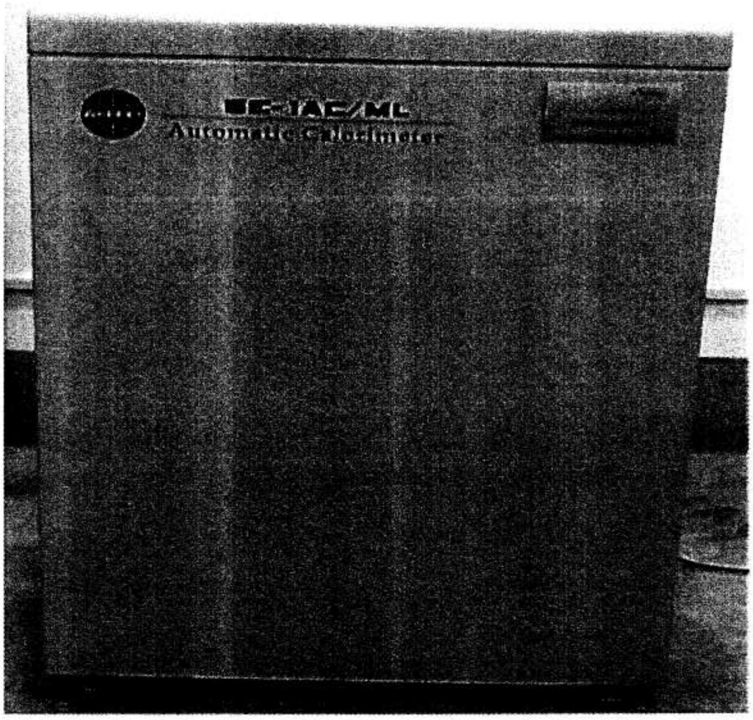

Figure.3 Automatic Bomb Calorimeter

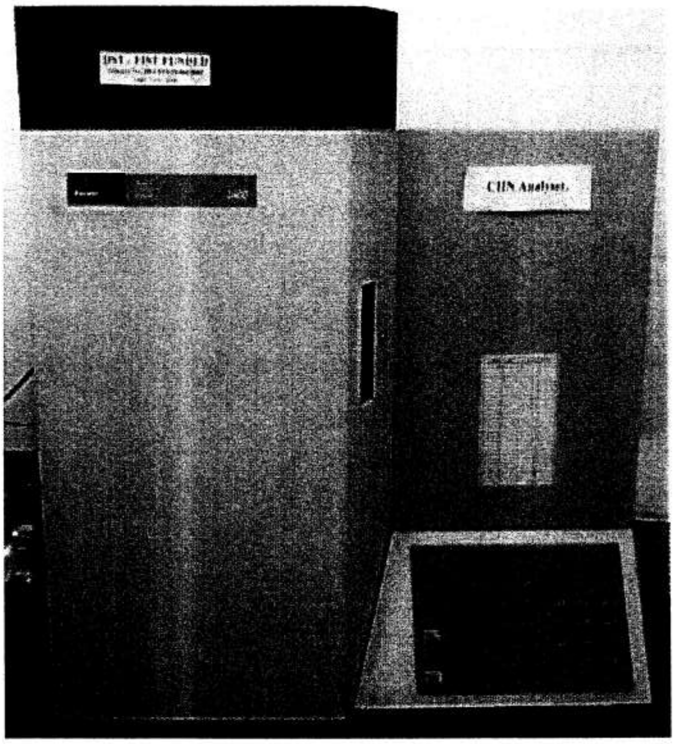

Figure.4 CHN Analyzer

Table 1: Proximate analysis of biomass

Biomass	Volatile matter % d.b.	Ash % db	Fixed Carbon % db
Bambusa tulda	80.00	4.50	15.20
Delonix regia	81.25	5.50	13.25
Azadirachta indica	81.75	5.60	12.65
Ficus lepidosa	82.00	5.80	12.20
Dalbargia sissoo	80.30	4.54	15.40
Psidium guajava	80.25	4.64	14.87
Samanea saman	80.80	4.78	14.53
Camellia sinensis	80.15	4.93	14.20
Polyalthia longifolia	80.80	5.07	13.86
Moringa oleifera	80.55	5.22	13.53

The Table 1 represents average proximate analysis data of ten biomass samples in triplicate. It was observed that *Dalbargia sissoo* had the highest fixed carbon (15.40 %) and *Ficus lepidosa* had the lowest fixed carbon (12.20 %). Ash value of *Bambusa tulda* was minimum (4.5) % and *Ficus lepidosa* was maximum 5.80 %. Excessive ash content of biomass adversely affects the performance of a gasifer because slag is severely formed at high temperature. It melts or fuses and subsequently, that may block the down draft gasifier throat as well as grate. This will result in poor performance of biomass gasifier system. *Bambusa tulda* had minimum volatile matter (80.00%) and *Ficus lepidosa* had maximum volatile matter (82%).

Table 2 presents different ultimate analysis results of ten biomass samples. It was found that *Psidium guajava* had the highest calorific value (18403 kJ kg^{-1}) and *Ficus lepidosa* had the lowest (15952 kJ kg^{-1}) among the tested samples. Calorific value of *Bambusa tulda* was in second position (18401 kJ kg^{-1}) in Table 2. Other eight woody samples had calorific value in between *Psidium guajava* and *Ficus lepidosa*. The approximate empirical bio-chemical formula for all ten biomass samples had been obtained from CHN/O analysis of data. Against one atom of carbon, *Bambusa tulda* has minimum 0.599 fractions of oxygen atom and 1.684 hydrogen atoms. The corresponding values for *Psidium guajava* is 0.608 (oxygen) and 1.1752 (hydrogen). However, *Delonix regia* has highest hydrogen (1.866) contents.

Table 2: Ultimate analysis of biomass

Biomass	C % by weight	H % by weight	N % by weight	O % by weight	CV (MJ kg^{-1})	Approximate empirical formula
Bambusa tulda	50.19	6.76	2.94	40.11	18.401	$CH_{1.684}N_{0\cdot050}O_{0.599}$
Delonix regia	46.78	7.33	2.82	43.07	17.502	$CH_{1.866}N_{0.051}O_{0.690}$
Azadirachta indica	47.38	7.14	2.84	42.64	16.603	$CH_{1.795}N_{0.051}O_{0.675}$
Ficus lepidosa	47.13	7.12	2.78	42.97	15.952	$CH_{1.799}N_{0.050}O_{0.684}$
Dalbargia sissoo	48.45	7.10	2.90	41.55	17.654	$CH_{1.745}N_{0.051}O_{0.643}$
Psidium guajava	49.85	6.83	2.89	40.43	18.403	$CH_{1.752}N_{0.049}O_{0.608}$
Samanea saman	49.48	6.90	2.86	40.76	17.982	$CH_{1.661}N_{0.049}O_{0.618}$
Camellia sinensis	49.12	6.97	2.82	41.09	17.831	$CH_{1.690}N_{0.049}O_{0.628}$
Polyalthia longifolia	48.77	7.06	2.77	41.40	17.332	$CH_{1.724}N_{0.048}O_{0.637}$
Moringa oleifera	48.41	7.11	2.74	41.74	17.211	$CH_{1.750}N_{0.048}O_{0.647}$

Nitrogen contents for all the samples are of course very small and may be neglected. *Dalbargia sissoo* has 1.745 (hydrogen) and 0.051 oxygen. Based on CHN analysis of these ten biomass samples, it may be concluded that there is not much difference in its C/H/N fractions and calorific values. Therefore, appropriately dried and sized all samples may be used for gasification. However, in a very special case, *Bambusa tulda*, *Dalbargia sissoo* and *Psidium guajava* may be potential feedstocks for downdraft gasification based on C/H/N contents and calorific values. This may generate combustible producer gas for thermal applications. However, *Bambusa tulda* is a very fast growing plant whereas *Psidium guajava* is not so. This gas obtained from gasification in turn may be used for process heating application in agro-based industries like tea, grain processing / drying, etc. after proper cleaning and cooling.

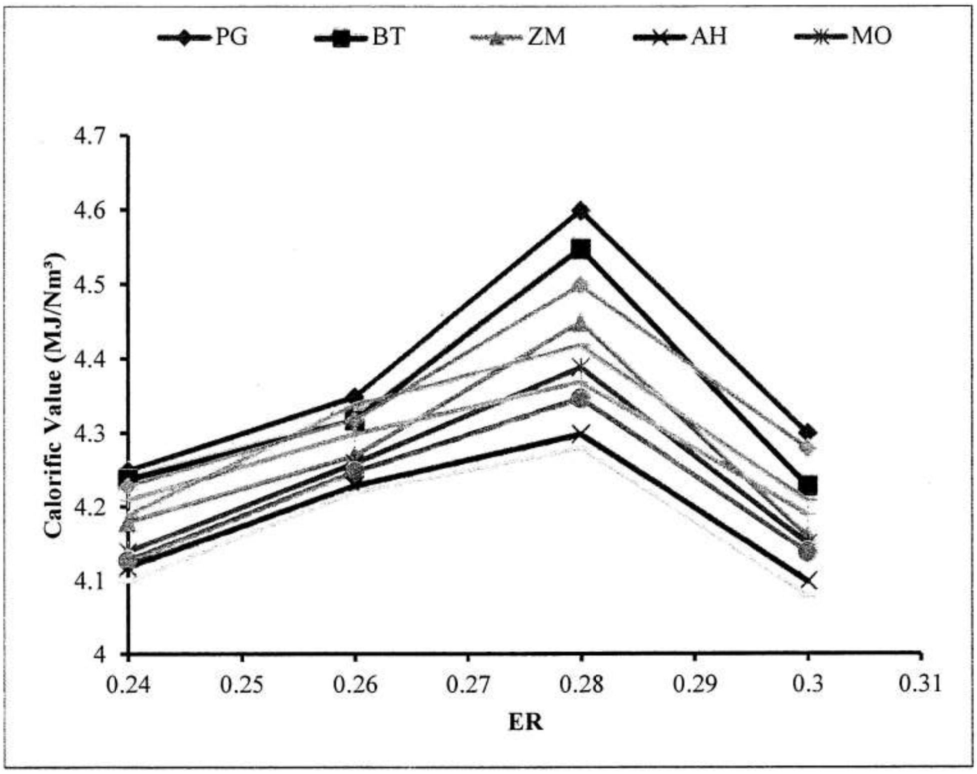

Figure.5 Variation producer gas calorific values with equivalence for different biomass gasification derived producer gas obtained GC.

Downdraft gasification of ten biomass samples and producer gas calorific values

After proximate and ultimate analysis of ten biomass samples, they were gasified in a 10 $kW_{thermal}$ downdraft biomass gasifier. The calorific values producer gas thus generated from gasification (at different air-fuel equivalence ratio (ER)) of these biomass samples have been presented in Figure 5. The calorific values of producer gas at different equivalence ratio had been determined with Gas Chromatography and Junker Gas Calorimeter. It has been observed that maximum producer gas calorific value was 4.6 MJ/Nm^{-3} for *Psidium giajava* gasification and minimum (4.28 MJ/Nm^{-3}) for *Ficus lepidosa* at gasification air-fuel equivalence ratio 0.30. The producer gas generated from other eight-biomass samples had calorific value less than 4.6 MJ/Nm^{-3} but greater than 4.28 MJ/Nm^{-3}. Beyond air-fuel equivalence ratio 0.30, the calorific values of producer gas generated from all the biomass samples declined probably because of combustion of a part of producer gas inside gasifier.

(iii) Has the progress been according to original plan of work and towards achieving the objective? if not, state reasons

Yes; Progress is original plan of work.

(iv) Please indicate the difficulties, if any, experienced in implementing the

Project: Since 2nd instalment was released late (At end of 2015), therefore, due to non-availability of Project Fellow salary component, the 1st Project Fellow left the project work in the last part of the year 2014. Due to lack of project manpower in the interim period (from late 2014 June 2015), the project progress was not as expected. Moreover, second instalment was released much later (26/08/2015) and first Project Fellow left on 27/07/2014 due to almost non-availability of salary component.

(v)If project has not been completed, please indicate the approximate time by which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the Commission on a separate sheet:
No; project was completed in the financial year 2015-2016.

(vi) If the project has been completed, please enclose a summary of the findings of the study. Two bound copies of the final report of work done may also be sent to the Commission

Findings and Conclusions:

The present study was conducted to characterize fuel properties (Calorific value and CHN/O analysis) of ten locally available biomass samples using an Automatic Bomb Calorimeter and a CHN/O Analyzer. It was followed by gasification studies at variable air-fuel gasification equivalence ratios with these biomass samples as feedstock. The following observations were made from these studies.

1. It has been observed that *Bambusa tulda* has the highest fixed carbon (15.20 %) and *Ficus lepidosa* has minimum (12.20 %).
2. *Psidium guajava* has the highest calorific value (18403 kJ kg^{-1}) and *Ficus lepidosa* has the lowest (15952 kJ kg^{-1}) among the tested biomass samples.
3. Calorific value of *Bambusa tulda* is in second position (18401 kJ kg^{-1}).

Against one atom of carbon, *Bambusa tulda* has minimum 0.599 fractions of oxygen atom and

1.684 hydrogen atoms. The corresponding values for *Psidium guajava* is 0.608 (oxygen) and 1.752 (Hydrogen) contents.

4. *Delonix regia* has the highest hydrogen (1.866) content and oxygen (0.069).
5. These samples (*Psidium guajava Bambusa tulda*, and *Dalbargia sissoo*) may be potential feedstock for downdraft gasifier for production of producer gas based on calorific value (4.6, 4.55, 4.50) MJ/Nm^{-3}. However, *Bambusa tulda* is a fast-growing plant (mature within 3 years) and other plants are not fast growing. Since calorific value of producer gas generated from other seven-biomass samples do not differ much (4.2 to 4.4) MJ/Nm^{-3}, therefore a mixed biomass feedstock for gasification may be prepared for thermal application.

(vii)Any other information, which would help in evaluation of work done on the project. At the completion of the project, the first report should indicate the output, such as

(a) Manpower trained: Three Project Fellows (Er. Ashutosh Das, Er. Netramoni Baruah and Er. Jugal Saharia was thoroughly trained on biomass gasification technology)

(b) Ph. D. awarded: Nil, However, six students did B. Tech final year project work on biomass gasification

(c) Publication of results:

1. Dutta, P.P., Baruah, D.C. Drying modelling and experimentation of Assam black tea (*Cammellia sinensis*) with producer gas as a fuel. *Applied Thermal Engineering* (Elsevier) 63: 495-502, 2014.

2. Dutta, P.P., Baruah, D.C. Possibility of biomass gasification in tea manufacturing industries in Assam, India. *International Journal of Renewable Energy Technology* (Inderscience) : 5(4); 310-322; 2014.

3. Dutta, P.P., Das, A., Pandey, V., Devi, M. Fuel characteristics of some locally available biomass as a potential gasification feed stock for thermal application. *Industrial and Engineering Chemistry Research* American Chemical Society) *53:19806-19813,* 2014.

4. Dutta, P.P., Das, A., Mishra, A., Kumar, B. and Singh, D.K. Some studies on a plate type heat exchanger. Paper presented at National conference on Recent Advancements in Mechanical Engineering, NERIST, Itanagar, Nov.08-09, 2013.

5. Dutta, P.P., Saharia, J., Kumar, T., Gupta A. and Singh, A.K. Gasification of Some Locally Available Biomass Using A Downdraft Gasifier. Paper presented at Second

International Conference on Recent Advances in Bio-energy Research', SSS National Institute of Bio-Energy, Kapurthala, Punjab, February 25-27, 2016.

6. Dutta, P.P., Saharia, J., Kumar, T., Gupta, A. and Singh, A.K. Fuel Characterization of Some Indigenous Biomass. Paper presented at Second International Conference on Recent Advances in Bio-energy Research', SSS National Institute of Bio-Energy, Kapurthala, Punjab, February 25-27, 2016.

7. Dutta, P.P., Saharia, J., Kumar, T., Gupta, A. and Singh, A.K. Gasification of Some Locally Available Biomass using a Downdraft Gasifier. Journal of Biofuel and Bioenergy 1(2), 208-207.

8. Dutta, P.P., Saharia, J., Kumar, T., Gupta, A. and Singh, A.K. Fuel Characterization of Some Indigenous Biomass. Journal of Biofuel and Bioenergy 1(2), 184-192.

(d) Other impact, if any: Nil

Dutta

SIGNATURE OF THE PRINCIPAL INVESTIGATOR

REGISTRAR/PRINCIPAL

(Seal)
कुलसचिव
तेजपुर विश्वविद्यालय
Registrar
Tezpur University

SIGNATURE OF THE CO-INVESTIGATOR

Attachment: I

1.1 Importance of tea

Tea is one of the principal and cheap soft drinks in the world. Per capita tea consumption in the world (0.3 kg y^{-1}, in 2009) is steadily increasing with augmentation of production in recent years. India is the largest producer of tea manufacturing about 1137 M kg next to China (1761 M kg). India exported about 236 M kg teas for revenue of about $ 480 million in the year 2012. About 20% (of total tea production is exported rest 80% is used for domestic consumption. Indian tea industry is about 200 years old and it has 579350 hectares total tea cropped area. Tea plantation area covered by small grower is about 163326 ha (up to 10.12 ha) and area under big grower is about 416024 ha (above 10.12 ha). Present average productivity of made tea is about 2000 kg ha^{-1} in India. About 50 % of Indian tea production is from tea estate situated in Assam. Therefore, tea processing is one of the traditional plantation based beverage industries in India providing direct and indirect employment to one million workforces. Tea crops provide the highest employment per unit arable area. It generates largest employment to the men and women of weaker section of the society. Tea industries generate indirect employment for tea- machinery development sector, agricultural chemicals, warehouse facilities, road transport, etc. These are in addition to the direct employment generation in tea production and processing sector. Moreover, tea industry is supporting machinery-manufacturing industries for supply and maintenance of tea processing machines. It also supports fertilizer and manure production chemical industries for tea cultivation practices. Thus, growth and development of tea industry is essential to ensure these economic benefits. Improved tea processing machinery development, adoption of energy efficiency and conservation practices, intervention of renewable energy for tea processing, etc., are the future need for sustainable development of this important agro based industrial sector in India. Tea plays a key role in Indian economy and society [2, 3].

It has been reported that tea productivity has increased by 60 % in the last two decades. However, internal consumption of tea has increased 7% annually. To maintain India's lead in tea export and upward foreign exchange earnings, stress on tea productivity coupled with stress on better quality and reduced production cost are essential. Employment of improved and innovative tea processing machinery, efficient and economic energy system are some of the key factors to be targeted to achieve such a goal [4]. Since tea manufacturing is highly energy intensive chemical engineering unit operation, therefore a brief description of black tea processing has been discussed below.

1.2 Black tea processing

Black tea processing consists of five unit operations namely withering (partial removal of moisture), rolling (size reduction), fermentation (biochemical reaction in presence of oxygen), drying and sorting (fiber removal and grading). Thermal energy is required in the form of hot air for withering and drying operations. Out of these two energy requirements, drying shares the major fraction of total thermal energy while withering requires very small amount thermal energy (5-10) % for black tea processing [5, 6]. The main sources of thermal energy in Indian tea industries are natural gas, coal, tea drying oil, and fuel wood. Woody biomass is more prominently used in South Indian tea industries. Assam and Northeast India tea industries use other three non-renewable thermal energy sources for black tea manufacturing. Specifically, the Southeast Assam tea industries significantly use natural gas and tea drying oil whereas Northern Assam tea industries use coal for tea drying energy requirement. The principal unit operations with a special reference to thermal energy consumption have been discussed below.

1.2.1 Withering

A standard tea shoot is consisted of two leaves and a terminal bud with (74-77) % moisture (dry surface) and (23-26) % solid matter. About half the solid matter is insoluble in water and it is made up of crude fiber, cellulose, proteins, fat, etc. Fresh tea after plucking is spread in thin layers to dry (withering) it partially for (12-20) hours. During first (4-8) hours, moisture loss is quite rapid and then it slows down for next (10-12) hours until the equilibrium is reached. Green leaf is loaded over the trough at the rate of (25-30) kg m^{-2} area up to 20 cm depth. About 2000 tonne of air is required to process one tonne of made tea and 75% of this air is required during withering. It has been reported that dryer exhaust air may be very efficiently used for withering green leaf in very dry weather.

Optimal withering air temperature and humidity are two important factors to determine quality of made tea and thermal energy requirement for this unit operation. Normally best quality tea is obtained for withering air temperature near to 27 °C with a dry bulb and wet bulb temperature difference 3 °C, at withering trough. As the air has passed through the exhaust, the hygrometric temperature difference should not be below 1.6 °C. Thermal energy is wasted rapidly if hygrometric temperature difference is more than 2.2 °C, at exhaust stream. The wet bulb temperature raises approximately 0.55 °C for (1.65 – 2.2) °C increase in dry bulb temperatures [6]. Moisture is usually reduced to (68-60) % particularly in tea factory situated in Assam. Normally, the tea manufacturing peak time ranges from May to November over the year. From May to September, the climate of Assam is hot and humid. Daytime room temperature is well above 27 °C and therefore addition of extra heat to withering air is not recommended for quality purpose. During rainy or winter season, additional thermal energy is required for withering purposes. Separate tea drying oil burners are used in certain tea factories for withering. Therefore, withering thermal energy requirement is met from varied sources as per availability and ease of operation [6].

During physical wither; there is a change in cell permeability by losing moisture. Bio-chemical changes occur inside leaf during chemical wither. It is achieved by blowing air sporadically or incessantly at low flow rate to keep leaf cool with loss of moisture for 4-18 hours [7]. However, chemical wither is necessary for producing full and round liquors. The duration could be reduced to 6-8 hours by holding leaf at 30 and 37 °C temperature and airflow rate of 0.01 $m^3 s^{-1}$ [8]. Immediately after plucking, the fresh leaf starts to lose water vapour. The stomata of the lower leaf surface begin to close [9-10]. The maximum initial drying rate is reported as 0.075 kg kg^{-1} (water per kilogram of green leaf per hour) [11].

1.2.2 Fermentation

During fermentation process, the most important quality property of tea is produced. This process is carried out simply by laying the *dhool*[1] (3.75 – 7.00) cm thickness at an average air temperature of 27 °C. On an average, fermentation takes (2.75 - 3.50) hours for completion at a temperature of 26.7 °C. A rapid fermentation at higher temperature suits certain tea; a longer fermentation at a lower temperature might suitable for other variety. By shortening or lengthening the period of fermentation, the degree of colour and quality may be varied. The compounds responsible for tea quality, such as theaflavins (TFs) and thearubigins were found to augment with fermentation time [12].

[1] Fermented tea undergoing drying is called *dhool*

1.2.3 Drying

The principal objectives of drying are to arrest the fermentation process to have desired properties and to obtain a stable finished product for preservation and marketing. Normally hot air generated by furnace and heat exchanger or flue gas mixed with air is used as a drying medium. Multi-stage tea drying process uses different drying medium temperature range in identified zones of dryer for fuel economy and quality. In general, two types of tea dryer are used in black tea manufacturing. They are endless chain pressure and vibrated fluidized bed types tea dryer. The understanding on the working of tea dryer is essential in relation to the present work. Therefore, both the types of dryers are briefly highlighted below.

Endless chain pressure type dryer

Conventional tea dryer is an endless chain pressure (ECP) type. This dryer is normally double firing type and is used traditionally in Northeast India tea factory for better quality. Normal range of drying air temperature is (82-99) °C with an exhaust temperature of (49-54) °C to stop stewing and case hardening of *dhool*. Exhaust air temperature 52 °C is ideal for both economy and quality of black tea produced. For double firing, initial temperature may be (93.3 – 104) °C whereas a temperature of (77 – 82.2) °C is suitable for CTC[2] and (71-77) °C for orthodox (special type of tea) tea in second drying depending on the moisture of first drying per batch drying. Average drying time in endless chain pressure type varies from (30-40) minutes. Though ECP dryer ensures better quality, to achieve better thermal efficiency and associated higher production rate there has been a shift towards vibrated fluidized bed dryer for processing of black tea after 1990.

Vibrated fluidized bed dryer

These dryers may have three or five zones in mixed flow or cross flow mode in addition to a cooling section. When a fluid flows upwards through a bed of granular particles, the pressure drop is initially proportional to the rate of flow. At a certain increased air velocity, the frictional drag of the particles become equivalent to the perceptible weight and bed begins to expand. This stage is known as onset of fluidization or incipient fluidization. Further boost in velocity causes the individual particles to separate from one another and float on stream of air. At this stage, the

[2] Curl tear and crush

system is said as a fluidized bed. Good thermal contact between the tea particles and drying medium results in improve fuel performance. Particle to particle attrition in a fluidized bed medium is minimized because its own fluid cushion bound each particle. This gives rise to blacker tea with better appearance and bloom as quality parameters. Plug flow fluidization is very much necessary for optimal energy consumption of black tea drying. Particles look like a boiling liquid in plug flow fluidized bed condition. The upper surface of the bed remains horizontal. The solids rapidly mix that lead to near isothermal condition in each zone of the bed.

The fermented leaf is loaded in grid plate of drying chamber. The top of the drying chamber is totally enclosed and two sets of centrifugal fans are provided with cyclones; one for re-firing and other is for dust collection operations. Plenum is situated beneath the bedplate where the air pressure is equalized as per requirements. Damper controls the direction of hot air entering the bedplate. It has dual purposes namely direction of damper determines the residence time of tea particles as well as evacuates the dryer completely at completion of drying. The fermented leaf enters into the drying chamber with a very high moisture content. It is reduced rapidly by admitting maximum volume of hot air for swift evaporation of moisture. The rapid loss of moisture causes increase in bulk density of fermented tea. Therefore, the material tends to move away from the feed end because it is displaced by incoming fresh fermented tea containing high moisture.

In addition to the understanding of tea dryers, the major factors influencing the tea drying process need also a brief discussion as below.

Factors affecting tea-drying process

The factors affecting tea drying process are, inlet air temperature, volume of air, fermented tea feeding rate into the dryer, drying time and outlet humid air temperature from dryer. Tea drying is normally carried out at a temperature range of (90 -140) °C depending on various factors to reduce withered tea average moisture from 67 % to (2.5-3) %. Normally, (1.5-2.5) kg moisture is removed against each kilogram of made tea in drying. When the fermented leaf enters into the drying chamber, it has very high moisture content (58-72) %. It is rapidly reduced in the first drying zone of the dryer. In the first drying zone, maximum air volume and high temperature is introduced. As a result, the material density is decreased and it tends to move away from the feed end towards exit of the dryer. Moreover, it is displaced by fresh material containing high moisture contents. As the material is fully dried, it is expelled into a cooling chamber at ambient temperature. Cooling of tea undergoing drying is essential for stopping case hardening as well as over drying. If only quality aspect is considered, then endless-chain pressure type dryer for tea drying is preferable over fluidized bed tea drying.

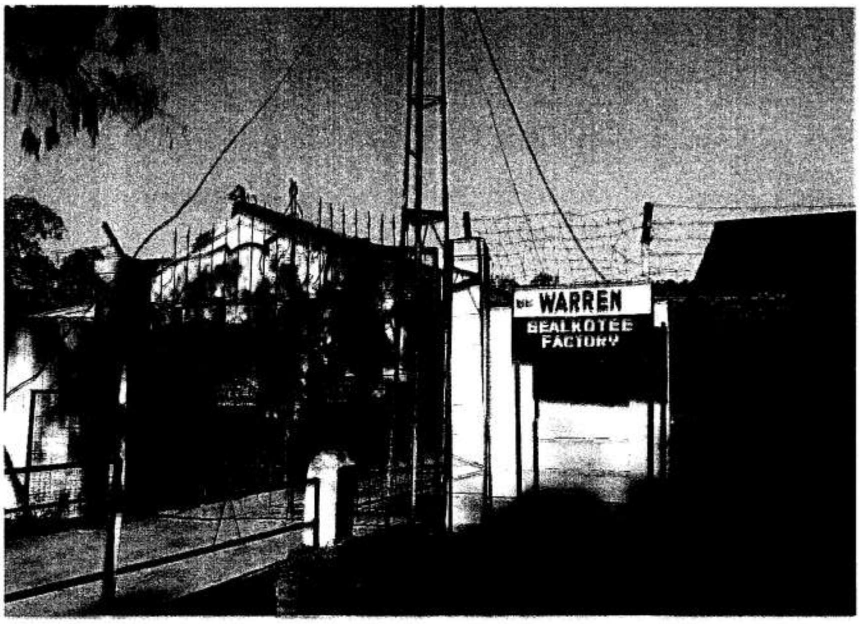

Figure.6 Visit to Tea Factory for Accessing Energy Consumption Pattern

1.3 Thermal energy utilization for black tea drying

Black tea drying is a highly energy intensive unit operation in tea manufacturing process. Different literature pertaining to tea drying energy consumption, drying efficiency, and energy conservation works are available both international and national level. Importance of thermal energy management in tea drying had been highlighted almost all the major tea processing regions including China [13], India [14, 15, 17], Japan [16] and Africa [18]. Coal and biomass are the predominant sources of thermal energy for tea processing in China. The studies indicated the requirement of appropriate management practices including introduction of improved drying machinery, utilization of waste heat, planning of unit operation, etc., for tea processing in order to conserve thermal energy. This would reduce unit cost of production.

Similarly, black tea manufacturing industries situated in Assam (India) had been reported to have variation in specific thermal energy consumption for different types of fuel. The minimum rate of energy consumption was 23.88 MJ kg^{-1} of made tea in oil-fired burners, 43.72 MJ kg^{-1} for coal-fired furnace and, 27.49 MJ kg^{-1} for gas-fired burner [14]. Energy efficiency improvement in air heater of a tea-manufacturing unit revealed that dryers were operating at very low efficiency due age-old design and improper selection of materials. Appropriate excess air control techniques might conserve 38 % of thermal energy in coal or biomass fired furnace with little or no investment. Therefore, optimal selection and discharge control of induced draft and forced draft fan was key factor for consideration. Moreover, furnace cum cast iron air heater (Figure.7) might be replaced with steam boiler for hot air generation [15].

Development of a primary drying tea roller with heat recovery devices in order to save energy in the primary drying process in tea manufacturing had been reported in Japan. The energy saving devices adopted were a heat exchanger that recovered heat from the furnace exhaust gas, heat pipes that recovered heat from the dryer exhaust air and a circulation path for the dryer exhaust air. The heat flow and energy saving effect of these devices used singly or in combination were calculated and discussed. A saving of between 12 and 29 % of the fuel consumption in the primary drying process was achieved with this waste-heat recovery device [16]. Figure 8 shows a natural gas fired improved burner for tea drying situated some tea esate factory of eastern Assam.

Figure.7 Coal fired air heater furnace

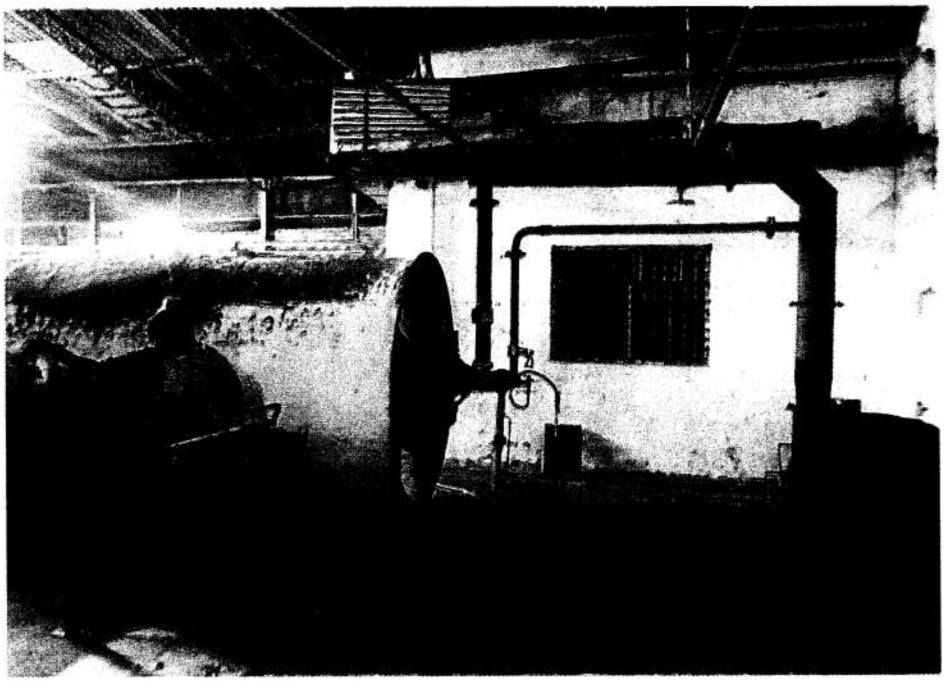

Figure.8 A Natural gas fired furnace for black tea manufacturing

The energy and economic issues related to the drying of tealeaves, with focus on the "zero physical wither system" being implemented in some areas in Africa, specifically in Kenya had been reported [18].

Sri Lanka also produces tea and importance of electrical and thermal energy management in tea drying is realized in that country [19]. Conservation of thermal energy required in tea processing and search for a new and sustainable source of energy seem to be universal requirements.

It has been observed that almost all tea-manufacturing industries in India have been using tradition fuel (Natural gas, Coal, Tea drying oil, and Wood) for tea drying process. It is evident that except wood, other three thermal energy resources are fossil origin based. Moreover, wood is burnt conventional fixed bed biomass fired furnace to heat air. Studies show that conventional fixed bed coal fired furnace and air heaters have been operating at a very low overall efficiency in most of the tea factories excluding a prominent part of upper Assam (Eastern part), India for long time. The reasons behind very low efficiency are, age old design of furnace and air heater, inconsistent quality of coal (low calorific value), inherently low heat transfer coefficient from flue gas to air in cast iron shell and tube heat exchanger. Moreover, with an increase in coal prices in international market, as well as operation of low energy efficient fixed coal fired furnace (Figure.7), the cost of production of black tea is augmented. Secondly, even though a natural gas burner (Figure.8) for tea drying is energy efficient, yet natural gas is not available to most of the tea factories in Assam, India. Natural gas being a fossil origin fuel, it is non-renewable in nature. Therefore, for economy and sustainability for tea manufacturing urgently need to use certain amount of green energy like biomass gasification derived producer gas, solar thermal energy for tea drying in place of inefficient fixed bed coal fired furnace and air heater.

Reference:

[1] Annual Book of ASTM Standard. Philadelphia: American Society for Testing of Materials **1983**, 19103.

[2] http://www.charhai.com/world-tea-consumption/ Accessed 19/06/2013.s

[3] Tea Board of India. Production final during (2012-2013) as compared to 2011-2012 http:// http://www.teaboard.gov.in/pdf/bulletin/Production_2012-13_Final.pdf, Accessed 10/06/2013.

[4] Tea Board of India (59^{th} Annual Report) http://www.teaboard.gov.in/pdf/bulletin/59-English-AR_12-13.pdf, Accessed: 19/06/2014.

[5] Panda, H. *The Complete Book on Cultivation and Manufacture of Tea*. Asia Pacific Business Press, New Delhi, 2011.

[6] Arunachalam, K. *A Handbook of Indian Tea*, Pondichery:1^{st} Eds, 1995.

[7] Tomlins, K.I., Mashingaidze, A. Influence of withering, including leaf handling, on manufacturing and quality of black tea – a review. *Food Chem.* **60(4)**, 573-580, 1997.

[8] Ullah M.R. A reappraisal of withering process in black tea manufacture. I. Physical and chemical wither and their effects on tea liquor. *Two and a Bud.* **31**, 20-24, 1984a.

[9] Orchard, J.E. Technical Report 1988-91. ODA TCO, Tea Research Foundation of Kenya, P.O. Box 820, Kericho, Kenya, pp. 126.

[10] Kramer, J.P. and Kozlowski, T.T. *Physiology of Woody Plants*, Academic Press, London, 1989.

[11] Jonson, A.L. *Tea Planter Handbook*, Tea Research Foundation Central Africa, P.O. Box: 51, Mulanje, Malawi, 1990.

[12] Muthumani. T., Senthil Kumar, R.S. Influence of fermentation time on development of compounds responsible for quality in black tea. *Food Chem.* **101**, 98-102, 2007.

[13] Ni, J.N., Zhou, H. Energy consumption and conservation in tea processing in China. *Renew Energ.* **2**(1), 1-5, 1992.

[14] Baruah, D.C., Bhattacharyya, P. C. Energy utilization pattern in the manufacturing of black tea. *Agricultural Mechanization in Asia Africa and Latin America*. **27**(4), 65-70, 1996.

[15] Balachandran, S., Rudramoorthy, R. Energy efficiency improvement in air heater of a tea unit – A case approach. *J Sci Industrial Res.* **67**, 151-153, 2008.

[16] Yoshitomi, H., Nakano, F., Takiya, H., Tanaka, S. Development of energy saving method for primary drying tea roller (part 1) - comparison of heat recovery devices. *J Jap Soc Agri Machinery*. **52**(1), 51-60, 1990.

[17] Kishor, N., Yadav, L.S. Coal, and oil energy requirement for drying fermented tea leaves. *New Agriculturist* (Allahabad, India). **12** (1/2): 81-83, 2001.

[18] Temple, S. J. Water in tea. *Quarterly Newsletter - Tea Research Foundation (Central Africa)*. **119**, 10-11, 1995.

[19] Zilva, R. de. The energy crisis in tea plantation. *J National Inst Plantation Manage.* **1, 2**, 127-135, 1981.

[20] Parikh, P. P. (IIT Bombay, Department of Mechanical Engineering). Qualifying, testing and performance evaluation of biomass gasifier and gasifier-engine system. Test procedure no. I: Ministry of New and Renewable Energy, Govt. Of India, New Delhi; 2000 Apr: Report No: 203-01-04/97-BM.

[21] Inserf. Junker gas calorimeter (Category No.IRI 023). Chennai (India): Instrumentation and Refrigeration India; 2008.

ज्ञान–विज्ञान विमुक्तये

Annexure - III

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002.

STATEMENT OF EXPENDITURE IN RESPECT OF MAJOR RESEARCH PROJECT

1. Name of Principal Investigator : Dr. Partha Pratim Dutta
2. Deptt. of Principal Investigator : Department of Mechanical Engineering

   University / College : Tezpur University
3. UGC approval No. and Date : 41-983/2012 (SR) & 25.07.2012
4. Title of the Research Project: *Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam*
5. Effective date of starting the project : 03/12/2012
6. a. Period of Expenditure : From 03/12/2012 to 31/03/2017

   b. Details of Expenditure :

Sl. no.	Items	Amount allocated (Rs.)	Total Grant (Rs.)	Expenditure incurred year wise (Rs.)					Total Expenditure (31/03/2017
				(2012-13)	(2013-14)	(2014-15)	(2015-16)	(2016-17)	
i.	Books & Journal	50,000/-	50,000/-	Nil	Nil	Nil	37,629/-	12,371/-	50,000/-
ii.	Equipment	7,00,000/-	7,00,000/-	Nil	1,00000/-	6,00000/-	Nil	Nil	7,00,000/-
iii.	Contingency	50,000/-	45,000/-	14,388/-	10,612/-	Nil	20000/-	Nil	45,000/-
iv.	Fieldwork/ Travel	50,000/-	45,000/-	12,873/-	12,690/-	Nil	13,412/-	Nil	38,975/-
v.	Hiring services (staff)	4,00,000/-	3,60,000/-	Nil	1,82,000/-	72,394/-	66,667/-	Nil	3,21061/-
vi.	Chemicals & Glassware	50,000/-	45,000/-	Nil	25,000/-	Nil	19,200/-	Nil	44,200/-
vii.	Overhead	62,800/-	62,800/-	31,400/-	5,512/-	25,888/-	Nil	Nil	62,800/-
viii.	Any other items	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	Total	13,62,800/-	13,07,800/	58661/-	3,35,814/-	6, 98282/-	1,56908/-	12,371/-	12,62,036/-
Summary		[Unspent amount (Rs.13,07800 – Rs.1262036 = Rs.45764/-) + Interest earned (Rs.66810/-)] = [Rs.112574/-]							
		Amount returned [Rs.112574/-]							

c. Staff

Date of appointment: 01/03/2013

Sl. No.	Items	From	To	Amount approved (Rs.)	Expenditure incurred (Rs.)
1.	Honorarium to PI (Retired Teacher @ Rs.18000/- month	2012	2016	Nil	Nil
2.	Project fellow: i) NET/GATE qualified – Rs.16000/- p.m. for initial 2 years and Rs.18000/- p.m. for third year. ii) Non-GATE/Non-NET – Rs.14000/- p.m. for initial 2 years and Rs.16000/- p.m. for third year	01/03/2013	27/07/2014	2,64,000/-	2,54,394/-
		22/09/2014	31/10/2014		
		24/11/2015	31/03/2016	96,000/-	66,667/-
3.		Total		3,60000/-	3,21,061/-

Finance Officer

Tezpur University

1. It is certified that the appointments have been made in accordance with the terms and conditions laid down by the commission.
2. If as a result of check or audit objection some irregularly is noticed at a later date, action will be taken to refund, adjust or regularize the objected amounts.
3. Payment @ revised rates shall be made with arrears on the availability of additional funds.
4. It is certified that the grant of Rs. **13,07,800.00** (Rupees Thirteen lakh seven thousand eight hundred only) received from the University Grants Commission under the scheme of support for Major Research Project entitled *Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam* vide UGC letter No. F. 41-983/2012 (SR) dated 25.07.2012 and 26/08/2015 has been utilized **Rs. 12,62,036/-** (Rupees twelve lakh sixty two thousand thirty six only) for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission and Rupees forty five thousand seven hundred sixty four only **(Rs.45,764/-)** remained unspent and Rupees sixty six thousand eight hundred ten only (**Rs.66,810/-**) is interested earned. Total Rupees one lakh twelve thousand five hundred seventy four only (**Rs.1,12,574/-**) is returned to UGC.

SIGNATURE OF PRINCIPAL INVESTIGATOR

REGISTRAR/PRINCIPAL

Registrar
Tezpur University **(Seal)**

SIGNATURE OF THE CO-INVESTIGATOR

Annexure – V

UNIVERSITY GRANTS COMMISSION

BAHADUR SHAH ZAFAR MARG

NEW DELHI – 110 002

Utilization Certificate (2016-2017)

Certified that the grant of Rs. Nil received from University Grants Commission under the scheme of support for Major Research Project entitled "*Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam*" vide UGC letter No. Nil dated Nil and Rs.58,135/- (Rupees fifty eight thousand one hundred thirty five only) is unspent balance from previous year and Rs.12,371/- (Rupees twelve thousand three hundred seventy one only) has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission. Rupees forty five thousand seven hundred sixty four only (**Rs.45, 764/-**) remained unspent and Rupees sixty six thousand eight hundred ten only (**Rs.66, 810/-**) is interest earned. Total Rupees one lakh twelve thousand five hundred seventy four only (**Rs.1, 12,574/-**) is returned to UGC through DD/Cheque No. SBIN717321937762

Dated: 17/11/2017

CHARTERED ACCOUNTANTS

09.12.2017

CA. SURAJIT CHAKRABORTY
(Proprietor)

SIGNATURE OF THE PRINCIPAL INVESTIGATOR	**REGISTRAR/PRINCIPAL (Seal)** Registrar Tezpur University	**STATUTORY AUDITOR (Seal)**

SIGNATURE OF THE CO-INVESTIGATOR

30.10.17
Finance Officer
Tezpur University

Annexure – V

UNIVERSITY GRANTS COMMISSION

BAHADUR SHAH ZAFAR MARG

NEW DELHI – 110 002

Utilization Certificate (2015-2016)

Certified that the grant of Rs. 1,56,000/- (Rupees one lakh fifty six thousand only) received from University Grants Commission under the scheme of support for Major Research Project entitled "*Characterization of producer gas generated from different locally available woody and non woody biomass through gasification by using Gas Chromatograph analysis and their potential application as renewable energy to supplement thermal energy requirement for tea processing industries in Assam*" vide UGC letter No. F. 41-983/2012 (SR) dated 26/08/2015 and Rs.59,043 (Rupees fifty nine thousand forty three only) is unspent balance from previous year and Rs. 1,56,908/- (Rupees one lakh fifty six thousand nine hundred eight only) has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission. Rupees fifty eight thousand one hundred thirty five only (**Rs.58, 135/-**) remained unspent is carried forward to the financial year 2016-2017.

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS
09.12.2017
CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

SIGNATURE OF THE PRINCIPAL INVESTIGATOR	**REGISTRAR/PRINCIPAL (Seal)** Registrar Tezpur University	**STATUTORY AUDITOR (Seal)**

SIGNATURE OF THE CO-INVESTIGATOR

30.10.17
Finance Officer
Tezpur University