Advanced Bioresidue Energy Technologies Society [ABETS]
Indian Institute of Science, Bangalore 560 012

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ABETS

Combustion Gasification & Propulsion Lab.
Indian Institute of Science
Bangalore 560012
abets@cgpl.iisc.ernet.in
http://cgpl.iisc.ernet.in

Summary of achievements during the year 2010-11

Thermochemical conversion and engines • Biomass to Hydrogen and Liquid Fuel • Producer gas engines • CO_2 capture
Field experience • Experience in food industry for replacing oil
Other areas • Power generation using biogas • Precipitated Silica for industrial purpose
Further on • Waste to energy

Details follow.

Research Highlights

There has been expansion in the field implementation of the technologies developed in the laboratory, in (a) Biomass gasification, (b) Producer gas engines, (c) Activated carbon from the gasifier, (d) Precipitated Silica from rice husk ash and (e) biomass stoves for various applications. Some of the important research contributions are highlighted below.

Gasification

It has been challenging to ensure multifuel capability of the gasification system to handle different biomass and this is **probably the only system design in the world** which uses various agro residues for generating producer gas. This has been possible due to the innovative reactor design and the engineering of the components.

Use of coconut waste briquettes for gasification

One of the projects aiming to install 6 MW power station was interest to use coconut tree residues for gasification. The testing involved using briquettes from coconut frond for generating producer gas for engine application. Commercially manufactured briquettes were obtained and were characterized for ash content, moisture content, particle density and bulk density. Standard procedure was used to determine the above parameters. Table-1 highlights the properties of the briquettes

Table 1: Properties of the fuel used

Properties	Values
Moisture content, %	17
Ash content, %	8.86
Particle density, kg/m^3	1064
Bulk density, kg/m^3	560
Diameter of briquettes, mm	60

The 80 kg/hr gasification system used consists of a reactor, cooling and cleaning system. The gas generated was flared. Briquettes were sized to about 50 mm long and were used. During this period, the fuel consumption rate, ash extraction rate, gas composition and also the gas quality before the filter was monitored. Table-2 summaries the operations.

Table 2: Details on the operation

Hours of operation	Briquettes used kgs	Char extracted kgs	% char extracted
6	368	24	6.5
24	1210	114	9.4
4 .5	83	15	17.9
(Total) 34 .5	1661	153	9.2

Figure-1 provides the gas composition measured during the operation and the calculated calorific value. The average gas composition has been CO ~ 19.3 %, H_2 18.8 %, CH_4, 1.84, CO_2 16.7 and rest N_2. The average calorific value is about 4.8 ± 0.4 MJ/kg. It is clear that even though there are some variations in the concentration of individual species, the calorific value is nearly constant.

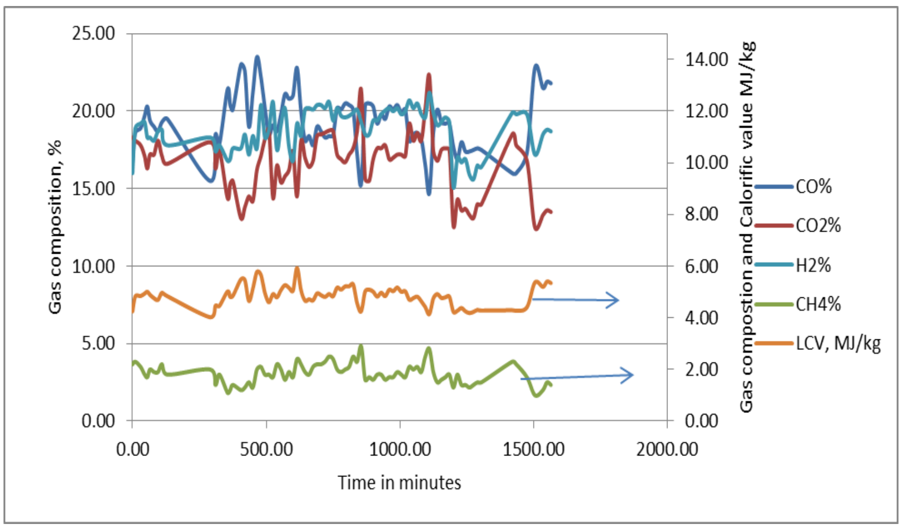

Figure 1: Gas composition with time

Reactor pressure drop is an indication of the bed behavior. Figure 2 depicts the pressure drop across the reactor over 28 hours of operation at a biomass consumption rate of 50 kg/hr. Nominal pressure drop has been about 60 mm of water.

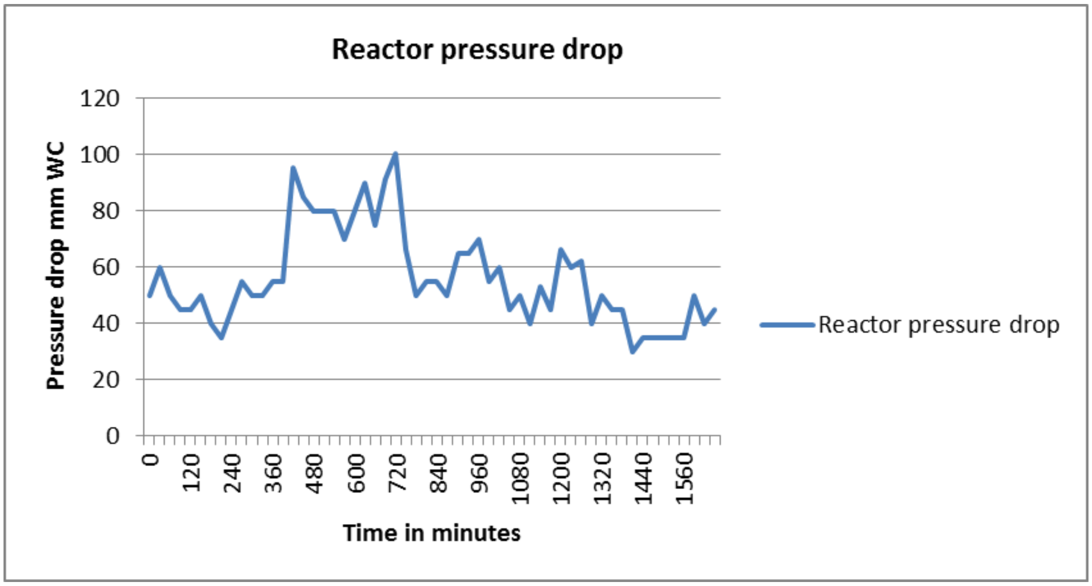

Figure 2- Reactor pressure drop during continuous operation

Figure - 3 provides the details about the biomass consumption and ash extraction.

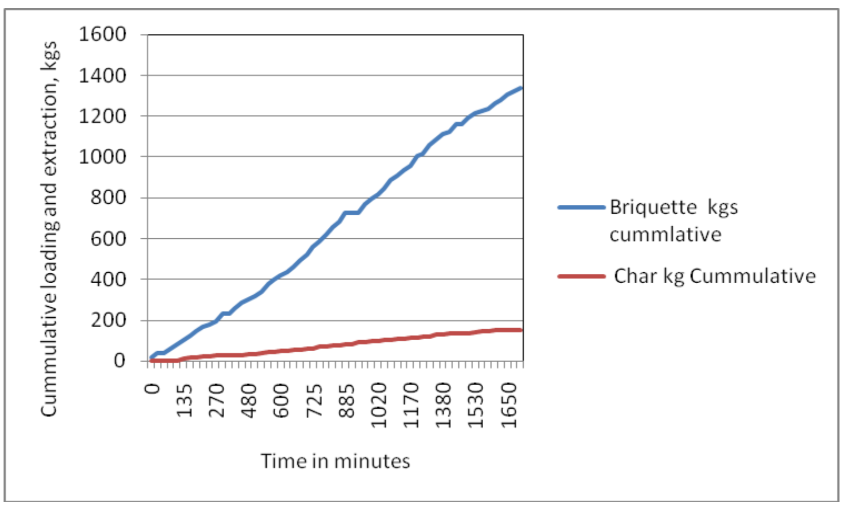

Figure 3 - Biomass loading and char extraction

Ash extraction was been found to be in the range of 9 to 11 % and the carbon content in the ash is found to be about 40 %. Cyclone collected about 4.4 kg carbon dust over 28 hours of operation, amounting to about 1200 mg/m^3 of gas and the particle size distribution is 50% below 50 microns, 10% below 13 microns and 90% below 161 microns.

Summary

- The total 34 hours of test run including a 28 hour of continuous operation with coconut fond briquettes went on smoothly
- No incidence on void formation or blockages reported
- The bed movement was very smooth
- The gas composition measured showed a very good quality gas with an average calorific value around 4.8 MJ/kg
- The briquettes are hard and did not crumble on handling
- The average briquette consumption during the continuous run remained at around 50 kg/Hr
- Char extracted during the continuous run period is around 11%
- The reactor pressure drop remained more or less steady during the test run period recording a healthy operation
- Power interruptions happened twice during the continuous run period
- Tar and particulate in the cold gas before the filter: Tar 4.8 ppm, particulate: 68 ppm
- Cyclone dust particle size distribution was measured as: 50% below 50 microns, 10% below 13 microns and 90% below 161 microns

CO_2 capture using gasification

This work focuses on conversion of CO_2 to CO, using CO_2 from the combustion of fuels in an engine or a combustion system exhaust, as a co-reactant. Using CO_2, the opportunity exists to adjust the ratio of the H_2/CO in syngas produced by selecting the concentration of CO_2 fed into the reactor system resulting in operational and economic advantages. In Fischer Tropsch (FT) reaction, product selectivity shifts to heavier products and to more oxygenates with increasing total pressure. Increasing H_2/CO ratio in the reactor results in lighter hydrocarbons and a lower olefin content. This indicates that conversion of CO_2 to CO in the gasifier would play an important role during the production of syngas for the generation of FT fuels.

The current research is to introduce CO_2 obtained from a typical diesel engine exhaust into open top downdraft gasifier, and converting it to CO, resulting in varied H_2/CO ratio in the gas produced. At the same time, above mentioned method may also be looked as a way to enhance the overall efficiency of system and reduce the CO_2 emissions, hence contributing towards environment security.

Set of experiments were conducted in a 10 kg/hr open-top downdraft gasifier. Ash extraction provision was fixed at the bottom of the reactor. This ensured continuous operation for longer durations. Data acquisition systems were put in place:

- 0.2 mm thick K-type thermocouples were placed at 100 mm distance in the reactor.
- 'Cubic Wuhan gas board' gas analyzer and 'SICK Maihak-S 517' gas analyzer were used to measure gas composition of CO_2, CO, H_2, CH_4 & O_2. Gas analyzer data were taken at an interval of every 30 seconds.
- Rotameter was used to measure CO_2 flow and venturi was used to measure Syngas flow.

Casuarina wood chips were used as a fuel for gasification. All the wood chips were dried at 373 K prior to gasification process. The result of ultimate analysis of dried casuarina wood samples was obtained from CECRI, India and is listed in Table-3 . The chemical composition of sample wood chip is $CH_{1.62}O_{0.88}$

Table 3: Ultimate analysis result of dry casuarina wood

Element	Mass fraction (%)
Carbon	42.83
Nitrogen	0.12
Sulphur	0.42
Hydrogen	6.24
Oxygen	50.39
Molecular Weight	27.89

Exit gas flow rate and air flow rate were measured using a pre-calibrated venturimeters. So, at any point of time any changes of air flow-rate into the gasifier were adjusted using a control valve, thus maintaining desired input mass flux rate of air or mixture of air, CO_2 and O_2. Char was loaded initially up to 300 mm height. Dry biomass (casuarina wood chips with moisture content < 5%) were fed above the char bed. Char bed was ignited from ignition ports and a blower was used to induce air flow inside the reactor. Reactor was kept under negative suction pressure throughout the experiments to maintain air flow at required rate. Once flame reached the wood particles; temperature, flow and gas composition data were recorded. After 45 minutes of air gasification, exact amount of CO_2 was injected through regulated flow meters from pressurized CO_2 cylinders, by mixing with air at the top.

Experiments were conducted initially with air as the gasification medium, followed by injection of measured quantities of CO_2 along with air, as a co-reactant, to analyze CO_2 conversion levels. During gasification process, once the hot char bed was established; input air mass flux rate was fixed to desired value. Producer gas flow rate, gas composition and bed temperature at different heights were recorded. After 45 minutes of stable operation, CO_2 and O_2 were introduced, along with air, maintaining the mass flux rate. With the introduction of CO_2, change in gas composition and producer gas flow rate were noted. Introduction of CO_2 induces endothermicity in the system due to following reactions:

Boudouard reaction:

$$C + CO_2 \Leftrightarrow 2CO - 172.6kJ/mole \qquad (1)$$

Water shift reaction:

$$CO + H_2O \Leftrightarrow CO_2 + H_2 + 41.2kJ/mole \qquad (2)$$

This resulted in reduced bed temperatures causing increased tar levels. Hence arrangement was made to introduce O_2 by mixing it with air and CO_2. The flow rates of O_2 and CO_2 were measured using pre-calibrated flow meters.

Results were obtained from equilibrium analysis using air as an oxidizer (Φ = 0.25) and subsequently adding CO_2 as a reactant. Over 40 % CO_2 conversion were obtained from equilibrium studies. Reduction in adiabatic temperature was also noted with increase in CO_2 fraction. Addition of CO_2 along with air reduced the O_2 fraction, leading to reduction in bed temperatures and thus the reaction rates. Boudouard reaction is endothermic in nature and conversion of CO_2 to CO requires high bed temperature to be maintained in reduction zone. Mixing CO_2 with air reduces the volume fraction of O_2 which leads to reduced reaction rates and subsequently lower conversion rates of biomass/char. Equilibrium analysis, maintaining O_2 fraction as 21% in inlet gas mixture, results in stable adiabatic flame temperatures at varying CO_2 fractions. Figure-4 shows the equilibrium analysis results for varying CO_2 input fraction. The results suggest reduction in percent of CO_2 conversion with increase in input CO_2 fraction.

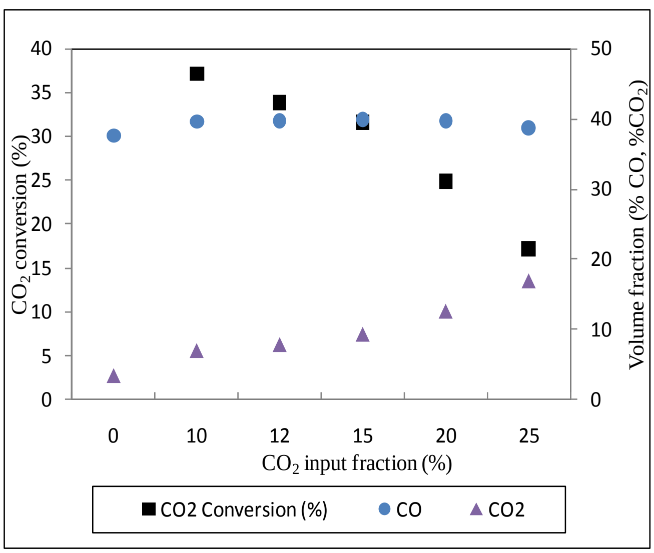

Figure 4 : Equilibrium analysis - CO_2 conversion, CO_2 and CO output with varying CO_2 input fraction

Equilibrium plots provided the tool to analyze this system, which in turn suggests the optimum working conditions. Results of equilibrium analysis were verified in experiments where drop in bed temperatures were observed with CO_2 as reactant compared with air alone. A drop in 50 K was recorded for 8.5% dilution of CO_2 with air. This issue of drop in bed temperature was resolved after increasing the inlet O_2 fraction to 21% (as that in air).

A gas evolution plot showing the distribution of the three gases (CO, CO_2 and H_2) that were monitored while conducting experiments with 15% CO_2 input (by volume fraction), is shown in Figure . It represents the air gasification composition with and without CO_2 injection. Changes in CO and CO_2 fractions occur when CO_2 and O_2 mixture is injected. After steady operation, CO_2 and O_2 injection is stopped and volume fraction of CO & CO_2 return to its original fractions. Figure-5 clearly shows the enhanced CO fraction which is the outcome of Boudouard and water shift reactions.

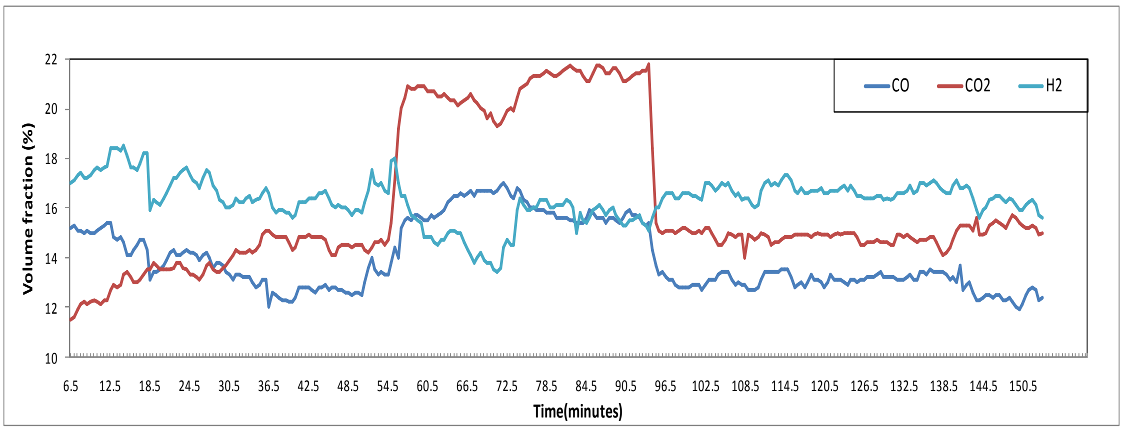

Figure 5 : Gas composition of producer gas with and without injection of CO_2

Figure-6 summarizes the results at different CO_2 input fractions. Data points obtained, were averaged through the several experimental data points, and were checked for consistency through repeated experiments. CO_2 conversion of 52%-55% was recorded while varying the CO_2 input fraction from 8.5 to15%. It was observed that there was no appreciable change in H_2 fraction in the output gas. The H_2/CO variation of 5%, varying CO_2 fraction from 8.5-15% was achieved. CO and CO_2 fraction followed the similar trend as shown in figure 3 with varying CO_2 fraction. It enhanced relative cold gas efficiency of system by up to 30%. CO_2 conversion rates were calculated on the basis of measured input air flow rate, output gas flow rate and char left in the gasification process.

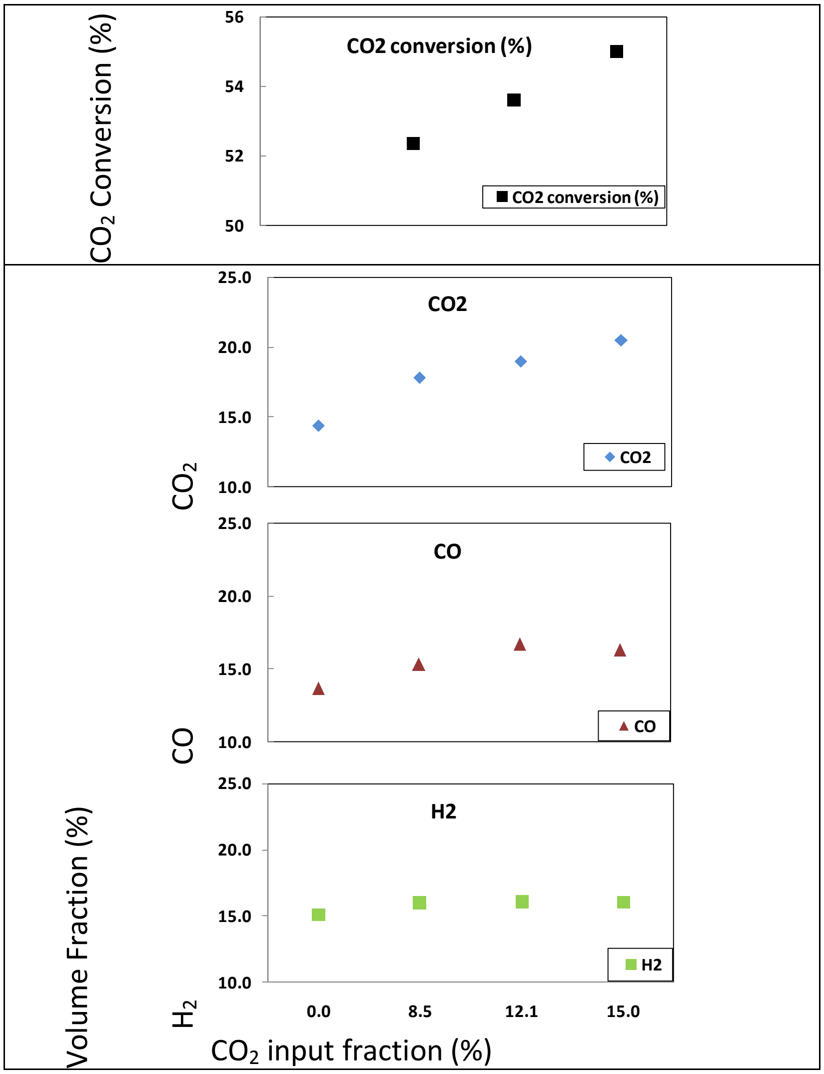

Figure 6 : Experimental results with varying CO_2 input fractions

Gas composition was measured on dry basis. To account for condensed H_2O during cleaning and cooling process, species balance of C, H and O was performed, based on exit gas composition, which accounted for 10% H_2O in the producer gas. H_2O was accounted for all the calculations of mass balance to calculate total CO_2 fraction converted and captured in process. CO_2 measurements were well accounted (conducting rigorous mass balance), proving validity of the CO_2 conversion levels.

CO_2-O_2-steam gasification permits the adjustment of H_2/CO ratio in producer gas, which plays a crucial role in the Fischer Tropsch synthesis, for the production of liquid fuels. Based on current work and results, further set of experiments injecting CO_2 with oxygen and superheated steam are planned. Injection of steam helps in enhancing H_2 content in syngas, and thus further enabling to acclimatize H_2/CO ratio for FT synthesis.

Producer engine

Experiments were conducted on a six cylinder Cummins India Limited (CIL) make natural gas engine operated under naturally aspirated conditions. The specifications of the engine are as described in Table-4.

Table 4 : Specifications

Make and model	CIL 6B59NA
Number of cylinders	6
Bore X Stroke	0.102 m X 0.120 m
Compression ratio	10.5
Ignition system	Spark Ignited
Engine type	Four Stroke
Aspiration	Natural
Rating	55 kW @ 1500 rpm
Alternator	3 Phase, 50 kVA

The engine, designed to operate on natural gas had its intake modified to accommodate the high fuel flow rates since air and fuel are supplied in near equal proportions when operating on producer gas. The engine, through the alternator is connected to an electric loading panel with resistive loading. The engine is operated from no load to full supported load with the full supported load being identified as the maximum load beyond which the alternator frequency drops off from 50 Hz. At each load, various parameters are measured as described below.

Pressure measurement

The in-cylinder pressure is measured using piezo-electric differential pressure transducer in an un-cooled spark plug of AVL make. The sensor through a charge amplifier is connected to an eight channel data acquisition unit having peak individual channel frequency of 800 MHz. The primary advantage of such a sensor is that no modifications to the cylinder head is necessary since the sensor is adapted into the spark plug itself as shown in figure-7.

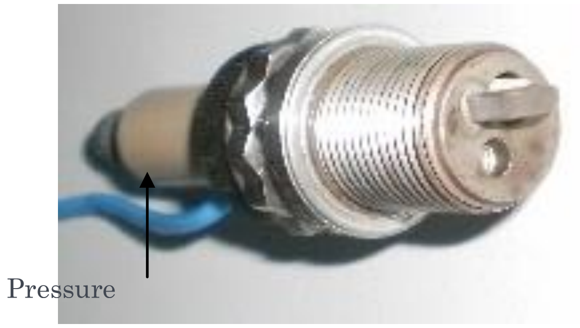

Figure 7. Spark plug adapted pressure sensor

The pressure transducer is connected to a data acquisition unit through a charge amplifier. The data acquisition unit has capacity to acquire data at the rate of 800 MHz per channel thus allowing for recording any transient traces. Since the pressure sensor is a differential sensor, it can detect only the change in the pressure content and not the absolute value. Towards converting the differential pressure into absolute value, the thermodynamic zero line correction as suggested by Hohenberg is adopted wherein the assumption of constant polytrophic coefficient is invoked for a certain range of compression crank angle.

Producer gas composition

The producer gas composition is continuously monitored for the entire duration of the experiment using SICK MAIHAK gas analyzer. The analyzer gives the gas composition on volume fraction basis and the composition in terms of CO, CO_2, H_2, CH_4 and O_2 can be monitored. The gas composition is monitored online for the entire duration of testing. The exhaust gas composition is measured using Quintox Flue Gas Analyzer. The analyzer gives the composition of various entities on dry basis in % volume / ppm levels. Temperature of mixture, flue gas, inlet and exit water temperature for the water jacket are all measured using a simple K type thermocouple. Air and gas flow measurement were carried out using calibrated venturimeter connected to differential pressure sensor.

Experimental investigation on the engine involved a preparatory step to operate the gasification system and allowing it to stabilize so as to deliver consistent quality gas. Typically, about an hour is the time required for the gasifier to attain steady state of condition from a fresh cold start. At any operating condition, the peak supported load was considered as that load beyond which the engine speed was dropping leading to a drop in the electricity frequency. The first sets of experiments were to determine the ignition timing that delivered best torque i.e. the maximum brake torque (MBT) timing. This was necessary since the properties of producer gas are different from that of natural gas for which the engine is tuned. Towards this, the engine was operated from no load to maximum supported load in steps of approximately 5kW for six different ignition timings 15, 18, 20, 24, 28 and 32 Deg BTDC. All subsequent experiments were carried out with ignition set at the MBT timing. Experiments were carried out from no load to full load at the MBT timing with and without the radiator whereby the radiator based cooling system was replaced by an external cooling system wherein coolant flow parameters like flow rate and inlet and exit temperatures could be measured. Using these information a complete energy balance for the engine was carried out. During each of the experiments, measurements were made with respect to the power output as indicated on the loading panel as well as voltage and line current, air and input fuel gas flow, exhaust emissions and temperature. Cooling water flow rate along with inlet and exit temperature were also recorded. On the emission front, particulate measurement was not envisaged because the feed itself was gas with low particulate matter.

This section presents the results from the experiments and the analysis of the data. All the pressure-volume and pressure-crank angle and heat release-crank angle diagrams presented are ensemble average values of 250 consecutive cycles. Any deviation is explicitly mentioned in the relevant discussion.

Gas Composition

Experiments on the 6B series engine were conducted over a cumulative time of around 30 hours spread over 5 days. The average gas composition obtained in volume percent was CO 16.04%, H_2 16.92%, CO_2 10.50%, CH_4 1.22%, and balance N_2. The average lower calorific value of the gas for this period comes to 4.2 MJ/m3. As can be observed, the gas quality seems to have suffered with a reduction in CO and H_2 content to the tune of around 3%.

Peak Supported Load

The engine supported a peak load of 29 kW at 1500 rpm. This essentially amounts to about 37% de-rating as compared to operation on natural gas. The de-rating is slightly on the higher side on comparing with the literature reported values [2]. This is mainly due to slight deterioration in the quality of the gas and the corresponding drop in the calorific value to 4.2 MJ/m^3 as against 4.5 MJ/m^3.

Maximum brake torque timing

Any engine, under a set of operating conditions has a particular ignition timing at which maximum torque is delivered. This timing is known as the Maximum Brake Torque (MBT) timing. The original ignition timing set for the engine operation on natural gas was 22 Deg before the top dead center (BTDC). Owing to the difference in properties of producer gas, the MBT timing had to be re-established. MBT was established by adopting the spark sweep test which is a well established procedure for determining the MBT timing. In the spark sweep test, the engine is operated at various spark timings within a particular range and the peak supported load at each of the loads is recorded. In the present work, spark sweep spanned a total range of 17 Deg from 15 Deg BTDC to 32 Deg BTDC.

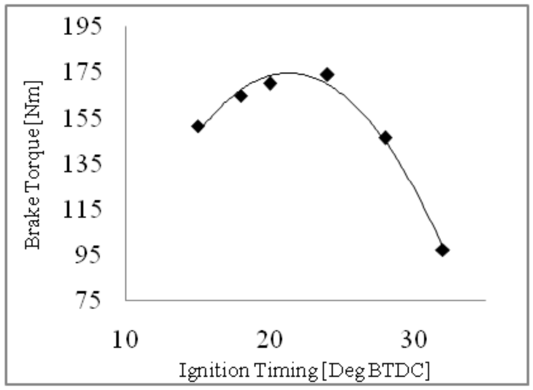

Figure 8. Brake torque variation with ignition timing

It is well established the fact that the brake torque peaks at the MBT timing and a plot of maximum brake torque plotted against ignition timing would give an indication of the MBT timing.

Figure-8 presents the variation of brake torque with ignition advance, bullets indicating experimental values and the line a representative cure fit. The trend is along the expected lines with the brake torque initially increasing and subsequently decreasing on advancing the ignition angle. The top region where the brake torque peaks is quite flat and the top most point in this region can be identified as the ignition angle delivering maximum brake torque or MBT. Experiments have yielded 24 Deg BTDC as the ignition timing and call for advancing the ignition timing by 2 Deg from the original setting. A careful observation of the trend indicate that the point of inflection for the torque curve is between 20 and 24 Deg BTDC.

Indicated Power and Cylinder Pressure Trace

Figure 9 presents the variation of the pressure as a function of crank angle for various loads at the MBT timing.

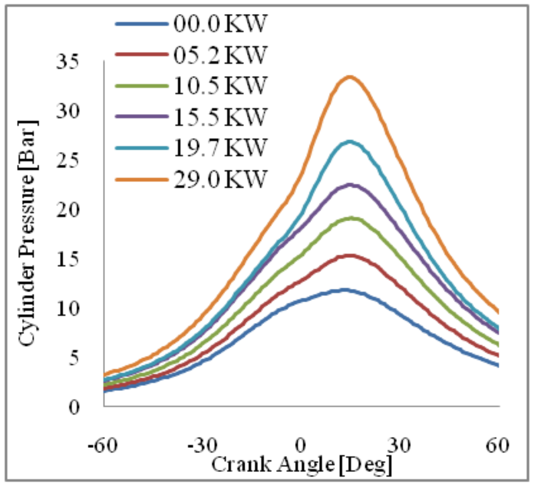

Figure 9: Pressure – crank angle trace at various loads

The pressure crank angle trace brings out one important factor with respect to the MBT timing. As per literature, if the peak pressure in the cylinder occurs at around 15 Deg after top dead center (ATDC) then the engine is set at MBT timing. The above figure and corresponding data give a position of peak pressure value of 16 Deg ATDC thereby confirming 24 Deg BTDC as the MBT ignition timing for the current operating condition and fuel. Plotting the pressure volume trace permits evaluation of indicated work as the area under the curve. Figure 10 presents the pressure volume curve that is used to determine the indicated work delivered by the engine at each of the loads. The area under the curve gives the work done by a single engine and symmetric behavior is assumed.

Table-5 presents the indicated and brake power along with the corresponding mean effective pressure values. The peak load IMEP at 5.64 bars is lower than the corresponding natural gas IMEP of 8.00 bars as reported earlier. Frictional losses in the range of around 11.5 kW are observed for the entire range giving a frictional mean effective pressure (FMEP) of around 1.5 bars which is consistent with the literature reported values for multi cylinder engines at 1500 rpm.

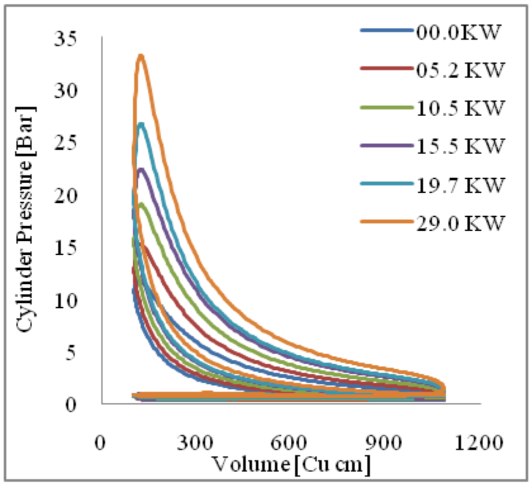

Figure 10: Pressure-Volume trace at various loads

Table 5 Power and Mean effective pressures

BP (kW)	IP (kW)	BMEP (Bar)	IMEP (Bar)
00.0	11.04	0.00	1.50
05.2	16.19	0.71	2.20
10.5	22.07	1.43	3.00
15.5	27.96	2.11	3.80
19.7	32.37	2.68	4.40
29.0	41.20	3.77	5.64

Efficiency and Specific biomass consumption

Figure-11 presents the variation of brake and indicated thermal efficiency with load, dots indicate the experimental values while the lines are second order polynomial fits to represent the trend.

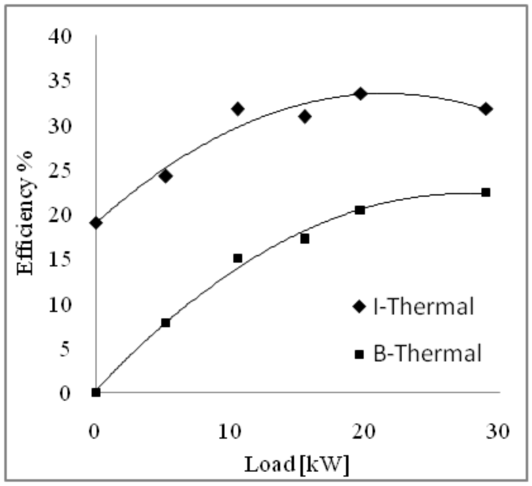

Figure 11: Indicated and brake thermal efficiency

A maximum brake thermal efficiency of 23% is observed amounting to 18% conversion efficiency from biomass to electricity with 80% cold gas efficiency for the gasifier.

-The specific biomass consumption gives a more direct indication of the amount of fuel consumed per kWh of energy developed. Figure-12 presents the variation of indicated and brake specific biomass consumption with load. Specific biomass consumption trend indicates a value of 1.30±0.05 kg/kWh based on shaft power output. Literature reports SBC value close between 1 to 1.2 kg/kWh for engine systems with overall efficiency values of 30%.

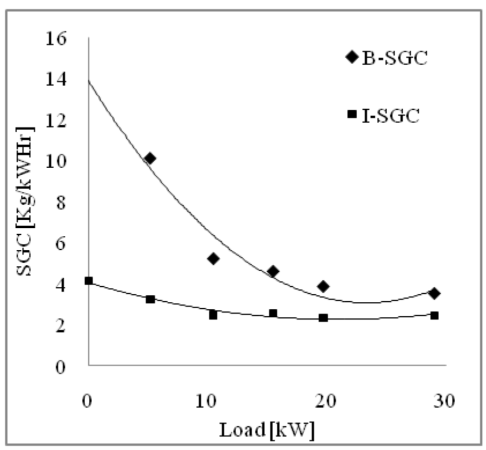

Figure 12 Indicated and Brake Specific Biomass Consumption variation with load

Energy Balance

Figure-13 presents the energy balance at the peak load of 29 kW.

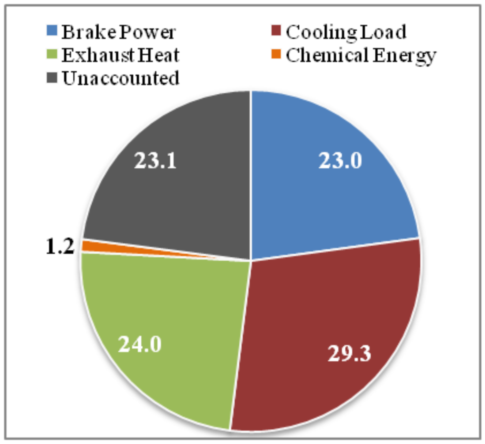

Figure 13: Heat balance at full load

As per literature, a typical spark ignited engine has the following energy distribution represented as percent of heat released in the cylinder; Brake power 25-28%, heat lost to the coolant 17-26%, heat carried away by the exhaust 36-50%, exhaust chemical enthalpy due to incomplete combustion 2-5% and miscellaneous or unaccounted portion around 3-10%. Along similar lines, Sridhar et al reports, on the performance of a diesel engine converted for producer gas operation at a compression ratio of 11.5 and ignition timing of 15 Deg BTDC distribution of energy as 29.7%, 45% and 25.3% for brake power, exhaust load and cooling + miscellaneous load respectively with the chemical enthalpy respectively. The recorded values in the present work indicate higher cooling and other loads but low exhaust energy. Heywood has indicated that bowl-in-piston kind of engines could experience nearly 10% higher heat transfer and the current engine being a shallow bowl in piston type, has correspondingly resulted in higher cooling load. On the chemical energy in the exhaust, one of the possible reasons for lower value as compared to reported values may be due to the advanced ignition. With the ignition timing at 24 Deg BTDC, an advance by almost 9 Deg cause higher in-cylinder temperatures and lower exhaust temperatures. It is a well established fact that, advancing the ignition timing leads to higher in-cylinder temperatures and subsequently higher heat fluxes across the cylinder wall as brought out by Demuynck et al and Shudo et al. Thus the present observation is consistent with the results from literature. This argument is further strengthen by the fact that, NOX in the exhaust has been observed at around 0.22 g/MJ while in the work by Sridhar et al values close to 0.05 g/MJ have been reported suggesting higher peak cylinder temperatures in case of advanced ignition. Higher in-cylinder temperatures also cause higher wall and engine component temperatures which is reflected in enhanced other losses. The chemical enthalpy due to incomplete combustion is well within the reported value.

Emissions

Table-6 presents the composition of exhaust emissions in terms of CO, HC and NO_X at full load and corresponding emission norms in India and Europe. The indicated values are corrected for 5% oxygen on dry basis in the exhaust.

Table-6: Emissions at full load against norms

NO_X [g/MJ]	HC [g/MJ]	CO [g/MJ]
Indian Norms		
2.56	0.360	0.970
European Union Norms		
1.30 (NO_X + HC)		1.390
Experimental Results		
0.22	0.011	4.904

Guidelines for Safe and Eco-friendly Biomass Gasification [35] specifies a limit of 500 mg/m^3 for NO_X and 650 mg/m^3 for CO while the recorded values stand at 123.5 mg/m^3 and 2659.7 mg/m^3 respectively for NO_X and CO. Though NO_X is well within the specified limit, CO seems to be on the higher side. This could be attributed to partial or incomplete combustion at higher loads. This aspect needs further investigation towards identifying a suitable catalytic convertor.

Collaborative research with Cummins India Limited

It was proposed to Cummins R and D group in the US that the existing engines have a very low efficiency and bmep operating in the field. The engine have turbo-charger designed for natural gas as fuel and there is a possible to improve the engine performance by optimizing the turbo-charger.

A program has been launched with CIL to address the turbo charger issue by carrying out detailed incylinder measurements and turbocharger. CIL is supporting with the necessary hardware for turbo-charging the engine.

A 500 kW lean burn engine designed for natural gas has been adapted for producer gas and is in the field for testing. This will be the first indigenous engine at 500 kW in India.

PG Carburetor for Small Power (<10kW) and Medium Power (>100kW) Generation

The standard diesel and petrol engines, after suitable conversion to work on gas were procured and installed with preliminary tests made on them. It was initially test-run on LPG and then tried on PG. A small sized carburetor design is being carried out. Consequent to a set of simulations and analysis, the suitable geometry of the carburetor will be arrived and would be fabricated and tested.

In parallel to this activity, a PG carburetor is under testing under simulated conditions for a 150kW engine. The necessary electronics developed at the laboratory has under gone lab tests under the simulated conditions. Once the engine is set out for PG operation, the carburetor would be tested along with the engine.

Design of hydrogen sulfide scrubbing system – new approach

ABETS has developed a process for hydrogen sulfide removal from gas mixtures especially from the biogas. At present about 6 plants have been installed with this technology where the hydrogen sulfide from the biogas is cleaned to less than 100 ppm (v/v) and the sweet gas is used for power generation. During this period of industrial application and operation, it was observed that the present design using packed columns for scrubbing and regeneration, though are functioning effectively, have some operational difficulties in the form of plugging of the packed towers with precipitated sulfur, which is a laborious process of cleaning the packing. Apart from this, it was also observed that there is a possibility of optimizing the design package to make it more robust with lower maintenance schedule and also possible reduction in the overall capital cost and the in-house power consumption. The present set of work has been carried out with above described objectives.

Scrubbing:

The ISET process developed by CGPL, IISc uses a chelated polyvalent metal ion which reduces the hydrogen sulfide to sulfur as a precipitate. The sulfur generated is filtered and recycled after regeneration.

Presently, packed columns using Rachig rings have been used for providing higher interfacial area for the reactions to occur and to ensure a hydrogen sulfide concentration is lower than 100 ppm. Though the packed columns have been doing the desired work say from 15 m^3/hr of gas flow rate with 5 % H_2S in the inlet gas to 600 m^3/hr of gas flow rate with 7.5% inlet H_2S concentration, have often been source of operational inconvenience in the form of frequent plugging, in spite of stand by columns being available. In order to avoid this frequent shut down of the columns, experimental work was carried out in the lab with a lab scale plant to understand the parameters with an impinging jet venturi scrubber.

Experimental set up

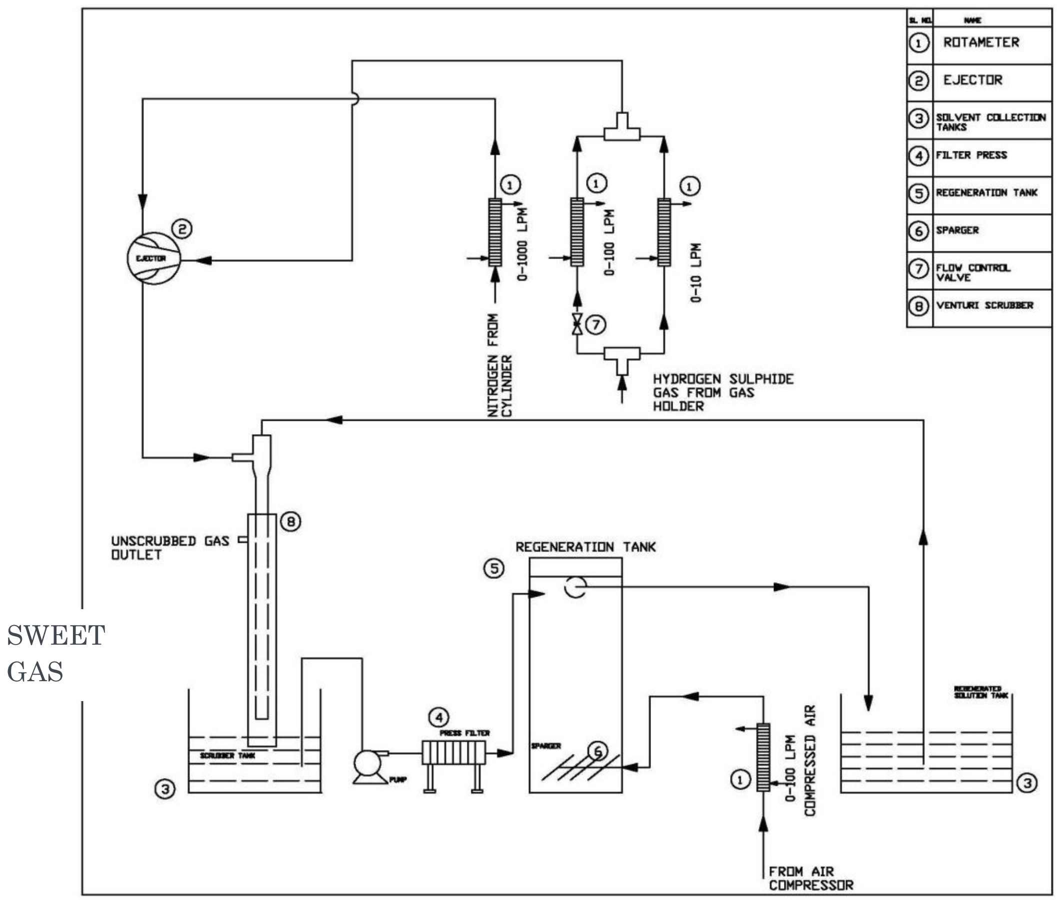

Figure 14: – Schematic of experimental setup.

The gas mixture consisted of nitrogen at a fixed flow rate between 110 to 130 lpm with H_2S flow rate varying between 3 to 15 lpm. Ferrous concentration was measured at the outlet of the liquid stream and hydrogen sulfide in the sweet gas was measured using electrochemical cell based H_2S analyzer. The liquid flow rate of 25 lpm and concentration of 0.1 N was kept constant throughout the experiments.

Results

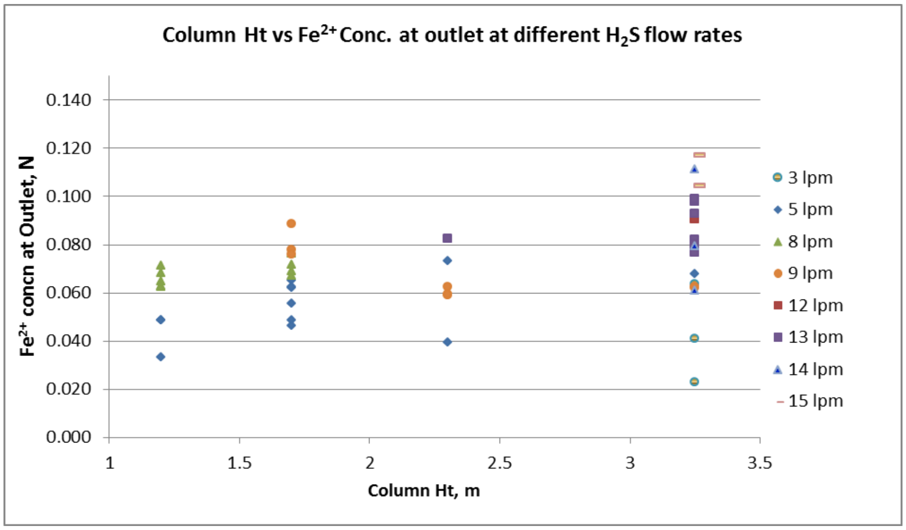

Figure15: Variation of Fe^{2+} concentration at outlet with column height

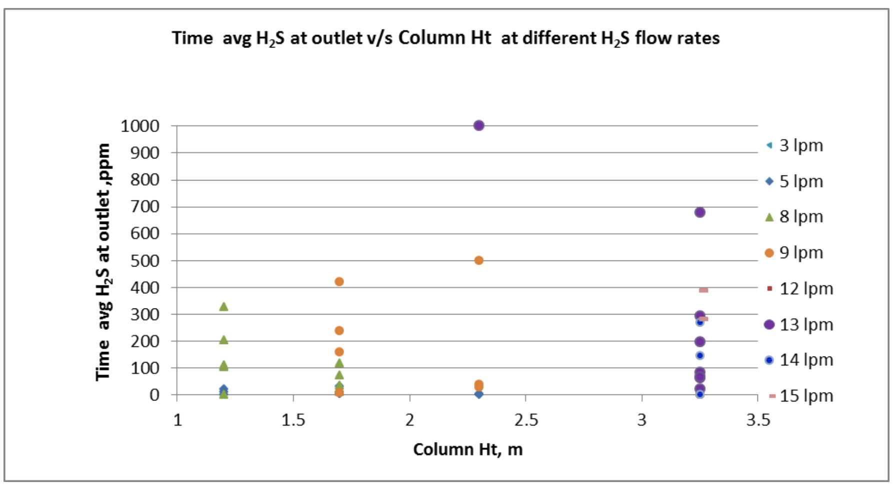

Figure 16: Variation of time average Fe^{2+} concentration at outlet with column height

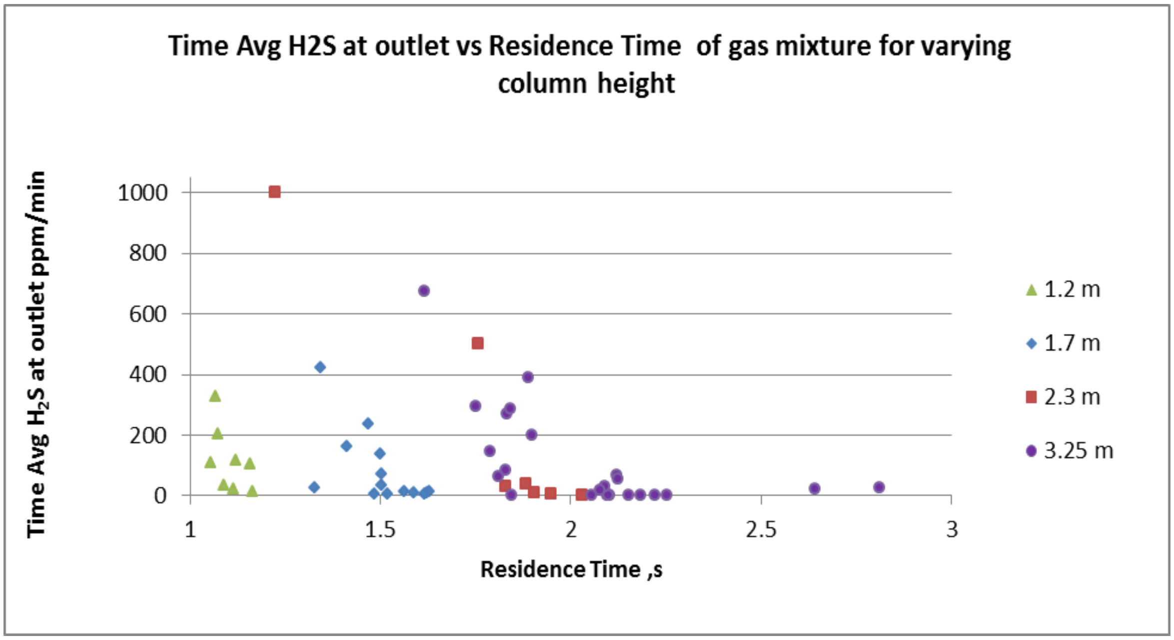

Figure 17: Variation of time average Fe^{2+} concentration at outlet with varying column height

Figures 15 and 16 gives the concentration of ferrous solution at different column heights and Figure 17 gives the H_2S concentration at the gas outlet at different column heights. It can be observed from the figures that at lower column heights though there is enough scrubbing solution available the residence time for reaction is not sufficient enough for complete scrubbing of the hydrogen sulfide. This is reflected in higher hydrogen sulfide concentration in the gas as seen in the plot 17. Figure 18 gives residence times to achieve almost zero hydrogen sulfide from in the gas and it can be easily observed that a minimum residence time about 3 seconds is required for achieving the objective.

Regeneration

Presently packed tower with counter current flow of air and the scrubbing liquid is being used for regeneration. The regeneration reaction being slow, the packed columns used presently are large in size. Hence a new design concept of using sparger for regeneration, where air is passed as bubbles has been explored. It was observed that air bubbles have to be fine and should not agglomerate as it moves up to enable to reduce the reaction time and there by the vessel size to make it meaningful as an cost reduction option. Further, it is also required that the sparger creating fine air bubbles does not offer large pressure drop, which would increase the power required for compressing the air to the required pressure. It was observed that hollow ceramic candles served the objectives and were used in the studies.

Results

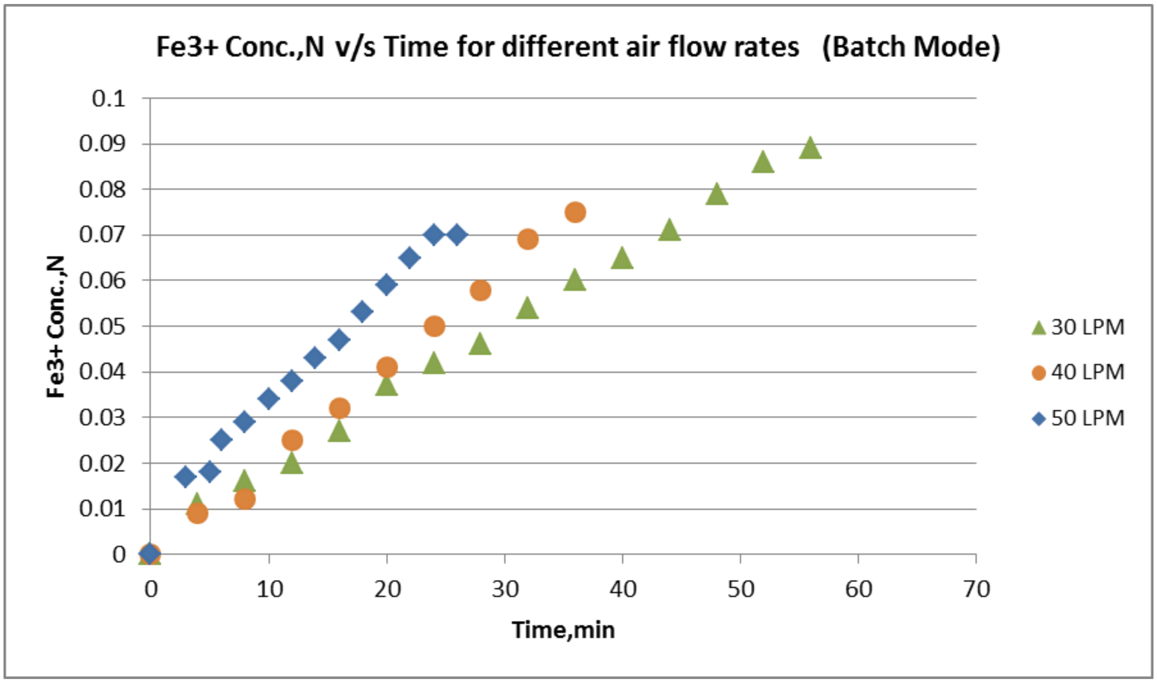

Figure 18: Plot showing effect of air flow rate on the residence time required for the reaction

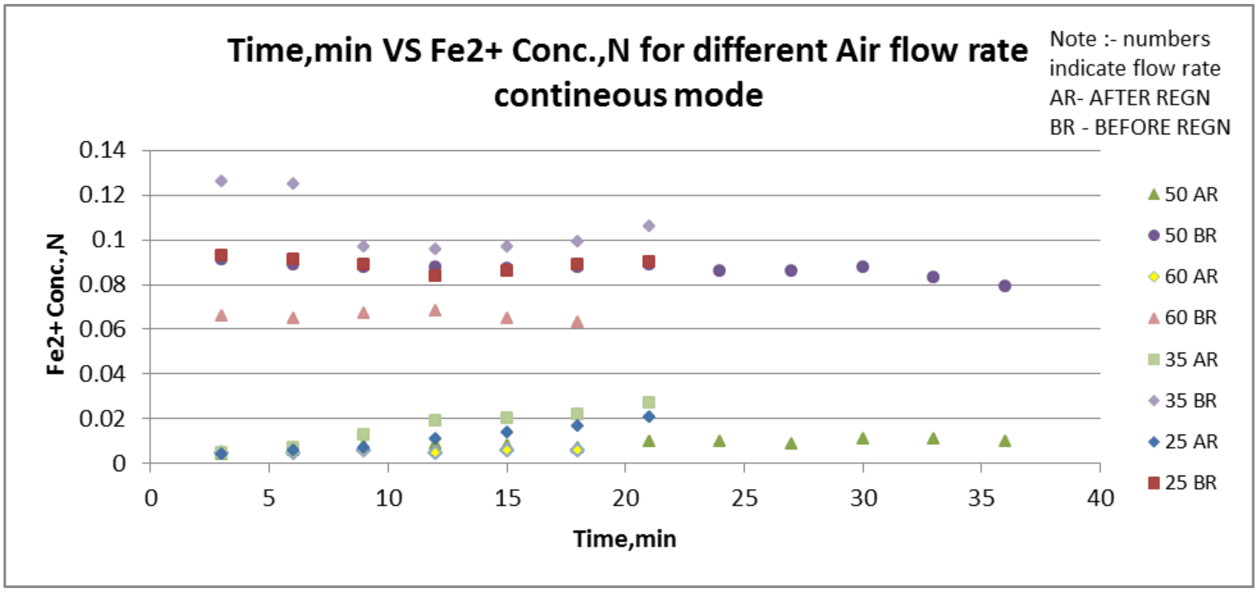

Figure 19: Plot showing Fe3+ concentration before and after regeneration in a continuous mode

It was observed from the experimental results (shown in Fig 18 & Fig 19) that at an air to H_2S ratio of about 3.3 i.e 50 lpm of air for about 15 lpm of H_2S scrubbed would require a residence time of about 30 mins. Lower flow air flow rates or lower air to H_2S ratio, would increase the residence time. Thus the air to H_2S ratio of about 3.3 is being considered optimum for the new design.

Technical Highlights

This year has seen significant research input the technology and consolidating the operations in the plant. Further development in the area of dual fuelling, gas engines, silica product, stoves and combustors. Progress made in these fields is described below.

Hydrogen Sulphide Scrubbing

A. Tilaknagar Industries, Srirampur, Maharashtra

The H_2S scrubbing plant of design capacity of 380 m^3/hr and 5 % inlet H_2S concentration has been set up at Tilaknagar Industries. The industry generates biogas from the distillery effluent. The gas is being treated with ISET process and the sweet gas is being used in a 2 X 350 kWe Schmit Enertec engines for power generation.

The plant has been in continuous operation since May 2009 and scrubbed about 2.2 million m^3 of biogas and generated about 3.8 million kWh of electrical energy till Nov 2010. The inlet H2S concentration is about 2.5 % and outlet is less than 50 ppm. The following table gives the plant performance in May 2009 to November 2010

Hydrogen sulfide scrubbing system performance at TIL												
Sr. No	Month	Gas scrubbed, m^3	Energy generated, kWh	Chemcial consumption, kg			Chemcial cost, Rs				Chemcial cost per kWh energy generated, Rs/kWh	Energy generated per m^3 of gas scrubbed, kWh/m^3
				EDTA	$FeCl_3$	Soda Ash	EDTA	$FeCl_4$	Soda Ash	Total		
1	May-09	79,377	132,553	625	187	263	100,000	7,480	4,734	112,214	0.85	1.67
2	Jun-09	195,356	308,237	975	300	417	156,000	12,000	7,506	175,506	0.57	1.58
3	Jul-09	192,074	321,901	1125	337	563	180,000	13,480	10,134	203,614	0.63	1.68
4	Aug-09	202,435	338,432	709	225	366	113,440	9,000	6,588	129,028	0.38	1.67
5	Sep-09	146,504	245,551	950	284	435	152,000	11,360	7,830	171,190	0.70	1.68
6	Oct-09	135,201	226,208	1000	300	485	160,000	12,000	8,730	180,730	0.80	1.67
7	Nov-09	156,889	262,826	1000	300	480	160,000	12,000	8,640	180,640	0.69	1.68
8	Dec-09	156,185	261,631	1000	300	480	160,000	12,000	8,640	180,640	0.69	1.68
9	Jan-10	141,294	236,802	1000	300	495	160,000	12,000	8,910	180,910	0.76	1.68
10	Feb-10	90,399	151,453	500	150	250	80,000	6,000	4,500	90,500	0.60	1.68
11	Mar-10	146,052	244,668	1000	300	510	160,000	12,000	9,180	181,180	0.74	1.68
12	Apr-10	157,193	263,334	1250	375	690	200,000	15,000	12,420	227,420	0.86	1.68
13	May-10	Plant not in operation due to non-availability of biogas										
14	Jun-10											
15	Jul-10	78,164	130,963	500	150	280	80,000	6,000	5,040	91,040	0.70	1.68
16	Aug-10	97,574	163,425	1000	300	530	160,000	12,000	9,540	181,540	1.11	1.67
17	Sep-10	38,542	64,554	250	75	410	40,000	3,000	7,380	50,380	0.78	1.67
18	Oct-10	113,038	189,325	1250	375	670	200,000	15,000	12,060	227,060	1.20	1.67
19	Nov-10	116,248	194,533	750	225	420	120,000	9,000	7,560	136,560	0.70	1.67
20	**Total**	**2,242,525**	**3,736,396**	**14,884**	**4,483**	**7,744**	**2,381,440**	**179,320**	**139,392**	**2,700,152**		

B. Sahyadri Starch.

Detailed engineering has been completed for scrubbing 550 m^3/hr of biogas with 2.6 % inlet H_2S concentration for Sahyadri Starch industries. The plant is incorporating new design concepts of venturi scrubbing and sparger based regeneration. The plant is expected to be in operation by December 2011.

Summary of field operation on Stoves

First Energy Private Limited are concentrating on commercial models meant for hotels and community kitchens. There are two varieties in this – K 30 and K 60. The fuel they are selling these days seems to have an ash content less than 6 %. This sets the calorific value of 15.5 MJ/kg

The performance is listed below.

Parameter		K-30	K-60	Unit
Amount loaded		6.5	18	kg
High mode	Operational duration	1.25	2.0	Hours
	Power level	5.2	9.0	kg/h
Medium mode	Operational duration	2.0	3.0	Hours
	Power level	3.25	6.0	kg/h
Low mode	Operational duration	3.0	4.25	Hours
	Power level	2.2	4.1	kg/h

Pellets – ash content 6.5 %, moisture content – 6 %, Calorific value = 15.5 MJ/kg

Emissions:

System	CO g/MJ	CO/CO_2 v	NO_x g/MJ	SO_x g/MJ
K- 30	0.42	0.01	0.002	0.008
K-60	0.35	0.006	0.002	0.007

FEPL has sold stoves 1500 (Andhrapradesh), 700 (Karnataka), 200 (Nagpur), 200 (Pune) and 150 (Tamilnadu), mostly replacing lpg used for cooking. They produce about 950 – 1000 tonnes per month of pellets in Islampur and Dharwad plants. The pellets are sold at Rs 12 per kg at this time. They are building a new larger stove called K 90 with about 30 kg single load of pellets.

Status of Projects

AGROGAS (ITALY) 70kWe

Project: Biomass Gasification Plant as a package of the system is addressed to suit the European condition emissions norms, after identifying the potential hazards and making a proper risk assessment

Capacity: 70kWe

Developed by: Combustion, Gasification & Propulsion Laboratory, Department of Aerospace Engineering, Indian Institute Of Science, Bangalore -560012, India.

Notified Body: European Inspection and Certification Company S.A

Local Body: Tech Europa Inspection and Certification Private Limited

Appreciable interest was shown by CREAR in establishing relationship between IISc and the group in CREAR. Over a period of year few probable areas of collaborative research were contemplated and arrived at. Major collaborative area was in the use of small scale gasification system for application in Italy. This resulted

- testing program in India for oil seed cakes towards gasification, establishing the gas compatibility for engine application and address issues related to emission norms for Europe
- setting up a demonstration project of gasification system of 70 kW capacity using the funding from IMLES (Italian Ministry of Environment).

A possible technology transfer was also proposed by CREAR, to which IISc suggested that it was open to it and the issues regarding packaging of the system to suit the European conditions needs to be looked into. After several exchanges a proposal towards 100 kg/hr gasification system coupled to a suitable for gas engine at 70 kW was given by IISc to CREAR. Few queries like the water treatment plant, emissions of gas engines and briquetting machine requirements were raised by CREAR. It was brought to the attention of CREAR that water treatment system was an integral part of the IISc Gasification system and actual requirements needs to be worked out based on the local norms. Emission data run on Producer Gas from IISc Gasifier was provided. The entire project was to ensure the system is manufactured as per the CE certification norms, with minimum automation to reduce manpower. CREAR proposed to IMLES for funding under the India – Italy cooperation.

Biomass gasification is a promising, energy efficient technology that can contribute significantly to renewable energy generation. The technology has advanced and being commercialized. The technology aims at safe best practices of biomass gasification, Health, Safety, Environment (HSE) and risks.

The CE mark, which is affixed to the product is considered proof that this product has met the requirements of the harmonized European standards, or directives. CE refers to communaute Europeen which literally means European community.
The objective of the gasification project is power generation of 70kwe in Italy after identifying and establishing the gas compatibility for engine application and address the uses related to emission norms for Europe. This package of the system is to suit European conditions after identifying the potential hazards and making a proper risk assessment.

To identify those parts in the equipment in the biomass gasification plant that are devices or assemblies covered by new approach directives and to supply the required CE marking and declarations of conformity (DOC) for these parts. Also the bought out items from third party will bear the CE marking and declarations of conformity.

The entire project is to ensure the system is manufactured

- As per the CE certification norms, with minimum automation to reduce man power
- Required Safety considerations, special features, alarms and audio visuals, interlocks / safety, essential safety requirements with all the directives, the color coding, labels and the symbols to be used are addressed in the project. The product safety testing will be carried out to meet the basic safety requirements as per harmonized standards and the risk associated with the product.
- Also the project is provided with different steps related to risk analysis, all the risks associated with the products with their corrective and preventive actions, and compliance to basic and essential safety requirement of products as per different directive associated.

Work completed :

a. Vendors who are competitive enough to deal with CE/ATEX norms for bought out items are identified
b. Material identification & testing for chemical and physical properties completed
c. Fabrication work of reactor, cooling and cleaning systems, water treatment, almost completed. Inspection team had visited the vendor of automated panel and satisfied about the technical competency, in line with the EN norms
d. Chiller manufacturer will meet the CE/ATEX norms

Precipated silica

Our Licensee M/s Usher Agro Limited is setting up a 5 ton per day silica plant at their rice milling plant site near Mathura in UP. The residue from the power plant using rice husk is will the input raw material for the silica plant. The detailed engineering for the silica plant is complete. The civil structure work is in the advanced stage. Orders are placed for the procurement of fabricated equipment and brought out items. The plant is expected to be complete by latter part of this year and the operations will start from early 2012.

National Focal Point for Biomass Resource Mapping

Software tools for satellite data utilization and online biomass assessment

The biomass assessment within a query based circular zone of interest has been developed for use with the online (internet based) digital atlas. Though an embedded image generated based on spatial biomass potential index including the biomass potential from agro-land, forest land and cultivable waste land helps to locate biomass hot spots, the biomass assessment needs to be done at the point selected for a practical approach. This has led to the development of this software tool that would allow the selection of a radius of interest and have the biomass power potential assessment made in the areal radius. The tool developed has undergone laboratory trials and qualification. After successful intranet tests, it would be deployed on internet.

Under an umbrella project of ABRC - BRMI (Biomass Resource Map of India) different new software tools that include geographic rainfall embedding, data extrapolation for rainfall and crops, adoption of SOI (Survey of India) data and correction of demographic layers have been under development and testing for suitable adaptation in the atlas.

Models for Biomass Supply Chain

Modeling of the supply chain process requires data – such as pelletizing or briquetting centers with their annual capacities, type of residues, their available quantity, prices, transportation expenses, base residue prices, biomass demand, biomass destination and their usages, biomass usage efficiency, domestic biomass fuel usage due to adoption of Cook stoves, logistics, societal aspects, parameters related to biomass re-entry, required outputs from the information system and any other relevant data. The necessary information system can be modeled and realized only over these data. The Modeling approach can be enhanced if the data at taluka level giving existing residue wise usage of biomass both for thermal and electrical power generation, current generation efficiencies, data on high yielding biomass plants for development of cultivable wastelands, existing usages, demand, existing power installations and any other relevant data are made available by suggestive studies supported by MNRE.

National Biomass Assessment for Agro, Forest and Wasteland

State-wise Biomass Data Based on Survey Data of year [2002-04] Considering All Biomass Class : All						
State	**Area (kHa)**	**Crop Production (kT/Yr)**	**Biomass Generation (kT/Yr)**	**Biomass Surplus (kT/Yr)**	**Power Potential (MWe)**	**Biomass Class**
Andhra pradesh	9983.2	21167.1	43893.2	6956.4	863.3	Agro
Andhra pradesh	3623.9	NA	5151.6	3484.4	487.8	Forest & wasteland
Arunachal pradesh	208.5	251.1	400.4	74.5	9.2	Agro
Arunachal pradesh	5467.4	NA	8313.1	6045.3	846.3	Forest & wasteland
Assam	3460.3	8250.6	11443.6	2346.9	283.9	Agro
Assam	2676.8	NA	3674.0	2424.2	339.4	Forest & wasteland
Bihar	7348.7	18817.6	25756.9	5147.2	641.1	Agro
Bihar	906.0	NA	1248.3	831.9	116.5	Forest & wasteland
Chhattisgarh	4758.2	6636.6	11272.8	2127.9	248.5	Agro
Chhattisgarh	8762.1	NA	13592.3	9065.8	1269.2	Forest & wasteland
Goa	154.2	489.5	668.5	161.4	20.9	Agro
Goa	153.4	NA	180.7	119.3	16.7	Forest & wasteland
Gujarat	8007.6	23895.7	29001.0	9085.5	1224.8	Agro
Gujarat	9030.3	NA	12196.3	8251.8	1155.2	Forest & wasteland
Haryana	5707.3	15226.2	29034.7	11342.9	1456.9	Agro
Haryana	294.7	NA	393.3	259.6	36.3	Forest & wasteland
Himachal pradesh	788.3	1504.0	2896.9	1034.7	132.6	Agro
Himachal pradesh	2259.8	NA	3054.6	2016.0	282.2	Forest & wasteland
Jammu & kashmir	749.4	773.8	1591.3	279.6	37.1	Agro
Jammu & kashmir	9838.0	NA	11461.7	7564.7	1059.1	Forest & wasteland
Jharkhand	1850.3	2459.5	3644.9	890.0	106.7	Agro
Jharkhand	3506.8	NA	4876.6	3249.8	455.0	Forest & wasteland
Karnataka	9683.6	43139.6	34167.3	9027.2	1195.7	Agro
Karnataka	6993.7	NA	10001.3	6600.8	924.1	Forest & wasteland
Kerala	2306.8	5561.0	11644.3	6352.1	864.4	Agro
Kerala	1235.4	NA	2122.1	1429.1	200.1	Forest & wasteland
Madhya pradesh	13167.3	17951.7	33344.8	10329.3	1373.3	Agro
Madhya pradesh	12802.2	NA	18398.2	12271.2	1718.0	Forest & wasteland
Maharashtra	18851.5	64336.1	47624.8	14789.6	1983.7	Agro
Maharashtra	13177.4	NA	18407.1	12440.4	1741.7	Forest & wasteland
Manipur	340.8	435.1	909.4	114.4	14.3	Agro
Manipur	1260.9	NA	1264.0	834.2	116.8	Forest & wasteland
Meghalaya	174.4	284.2	511.1	91.6	11.3	Agro
Meghalaya	1532.6	NA	1705.9	1125.6	157.6	Forest & wasteland
Mizoram	19.0	33.3	61.1	8.5	1.1	Agro
Mizoram	1638.8	NA	1590.9	1050.0	147.0	Forest & wasteland
Nagaland	179.6	276.1	492.2	85.2	10.0	Agro
Nagaland	786.4	NA	843.8	556.9	78.0	Forest & wasteland
Orissa	6667.6	12262.7	20069.5	3676.8	429.3	Agro
Orissa	6265.0	NA	9370.2	6084.8	851.9	Forest & wasteland
Punjab	6993.5	35934.0	50847.6	24842.9	3172.2	Agro
Punjab	229.1	NA	398.5	263.0	36.8	Forest & wasteland
Rajasthan	14851.4	16135.5	29851.3	8645.7	1126.7	Agro
Rajasthan	14135.0	NA	9541.6	6297.5	881.6	Forest & wasteland
Sikkim	58.0	69.1	149.5	17.8	2.3	Agro
Sikkim	372.8	NA	531.5	350.8	49.1	Forest & wasteland
Tamil nadu	4165.1	30415.4	22507.6	8900.0	1160.0	Agro
Tamil nadu	3187.2	NA	4652.4	3070.6	429.9	Forest & wasteland
Tripura	9.5	3.7	40.9	21.1	2.9	Agro
Tripura	831.0	NA	1035.5	683.4	95.7	Forest & wasteland
Uttar pradesh	15950.9	138945.4	60322.2	13737.9	1746.2	Agro
Uttar pradesh	3856.5	NA	5478.4	3672.0	514.1	Forest & wasteland
Uttaranchal	1015.7	7783.3	2903.2	638.4	80.9	Agro
Uttaranchal	2885.5	NA	4559.2	3055.3	427.7	Forest & wasteland
West bengal	6090.2	22807.8	35989.9	4301.5	529.3	Agro
West bengal	1113.9	NA	1430.7	949.0	132.9	Forest & wasteland
Agro-Total	**143540.9**	**495845.6**	**511041.0**	**145026.6**	**18728.7**	
F & W-Total	**118822.9**	**NA**	**155474.0**	**104047.4**	**14566.6**	
Total	**262363.8**	**495845.6**	**666515.0**	**249074.0**	**33295.4**	

Waste to energy

Research and Technology demonstration for converting screened MSW (provided by SGRRL) which includes non bio-degradable fractions, by shredding further to the required grade for producing RDF briquettes and further utilizing it in IISc Bio-residue Gasifier (IBG) for power generation using gas engine.

Status

Major componets are ordered and assembly is in progress. The fuel processing equipment, is being installed and commissioned during this month and trail operations on the briquette production will be taken up. The cooling cleaning system is designed and being released for fabrication.

Interaction with International agencies

Cuba

UNIDO has sponsored a project for demonstration of biomass gasifier at Cocodrilo in Isle da Juventad of Cuba. The package consists of 70 kg/hr open top down draft (IBG - 70) gasifier and 68 kWe diesel engine has been operational and one of the group is in touch with ABETS on certain component replacement which has failed.

Nigeria and Benin

Request for the proposal received from UNIDO for supporting the sustainable energy generation at

- 25kWe using agricultural residues especially corn cobs as fuel (Songhai Center, Benin)
- 25kWe using wood chips or mixed biomass as fuel(Abakaliki, Nigeria)

As a part of the project objectives, it is proposed to install 2 demonstration pilot project to generate power, using biomass as fuel, to meet the energy requirements of a small business communities based at Abakaliki, Nigeria and Songhai center, Benin. This pilot demo projects will have twin objectives:

- to replace diesel fuel based electricity generation through biomass gasification technology using gas-engines, and to meet the energy needs of local community on decentralized basis as a mini-grid and
- to demonstrate techno-economic feasibility and commercial viability of biomass gasification technology in local conditions and link with productive uses, and disseminate information to key stakeholders.

Thailand

The power plant at A+ Power, Thailand is based on IISc gasification system coupled to gas engines for power generation was commissioned. The intial trails suggests that the engine rating is about 650 kWe as antipicated and long duration trials are being planned.

Dr. Dasappa visited Birmingham, United Kingdom in Dec 2010 as a part of the Indian team to develop proposal on "India-UK Collaborative Research Initiative in 'Bridging the Urban and rural Divide"

Dr.Dasappa visit, Germany to present papers at the 19th European Biomass Conference & Exhibition, Berlin.

Mr. Subbukrishna and Prof. Paul visited Thailand for performance evaluation of the gas engine.

Prof. Paul visited Spain as a part of Indian delegation from DST

Awards

- Intelluctual Property cell at IISc had nominated Biomass Gasification Technology developed at IISc, for the Nina Saxena Excellence in Technology Award, 2011 instituted by IIT Kharagpur. The award ceremony was held on 18th August 2011 and the same was received by Dr. S Dasappa and Dr. N K S Rajan on behalf of the group. The award carried a Plaque and Rs. 51000.00

- The stove technology developed at IISc and transferred to BP which is currently being taken forward by First Energy Private Limited for commercialization has been selected gets into prestigious "Technology Pioneers 2012 World Economic Forum list"

From over 800 companies, 25 of them has been selected from, as innovative companies, by their visionary and entrepreneurial nature, are well positioned to address some of the world's challenges.

Excerpts from the **Technology Pioneers 2012**, World Economic Forum, September 2011. (http://www3.weforum.org/docs/WEF_TP_Brochure_2012.pdf)

First Energy Private's revolutionary cooking stoves help save the environment while making life more affordable in rural villages

Finding fuel for cooking is a major problem in many rural villages in developing countries. The most common fuel in India is wood or kerosene. Wood is often hard to come by and in densely populated areas there is the danger of stripping the local countryside bare. Kerosene is expensive and often contributes to air pollution and respiratory problems. First Energy Private Ltd's solution is an inexpensive, highly efficient cooking stove, which burns biomass pellets, known as "oorja" that are made from the compressed residue of agricultural by-products and rely on a radically new biomass gasification technology developed and patented by the Indian Institute of Science in Bangalore. The pellet stoves make it possible for an Indian family to serve a meal for five for roughly one rupee per person. When the demand for pellets began driving prices up, First Energy introduced technology to spur production locally. Not only are the stoves three times as efficient as conventional stoves, but they are also virtually smokeless. Estimates are that the pellets cut down carbon emissions and particulates in the air by up to 70%. Operating through some 3,000 village entrepreneurs and dealers, First Energy has sold stoves to some 485,000 households in five Indian states and contends that they have already saved around 32,000 tons of fuel. The goal is to reach one million households in the next three years and become a market leader in other developing countries, as well as a significant force in the fight to control carbon emissions.

The Huffington Post Steven Hoffer and Ileana Llorens First Posted: 9/1/11 07:10 PM ET Updated: 9/1/11 07:10 PM ET

First Energy produces cooking stoves under the "Oorja" brand that are "virtually smokeless" and more efficient than traditional alternatives. The company promises that its innovations can help people and small businesses in rural villages save time, money, and the environment "First Energy Private Ltd's solution is an inexpensive, highly efficient cooking stove, which burns biomass pellets, known as 'oorja' that are made from the compressed residue of agricultural by-products and rely on a radically new biomass gasification technology developed and patented by the Indian Institute of Science in Bangalore," writes the WEF. "The pellet stoves make it possible for an Indian family to serve a meal for five for roughly one rupee per person."