EVALUATION OF GASIFIER BASED POWER GENERATION SYSTEM USING DIFFERENT WOODY BIOMASS

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ABSTRACT

Biomass based power generation system having power rating of 10 kW was established at Department of Un-conventional Energy Sources, College of Agricultural Engineering and Technology, Dr. Panjabrao Deshmukh Agriculture University, Akola. The system was evaluated for power generation using *Prosopis juliflora* (Vilaytee babool) and *Leucaena leucocephala* (Subabool) wood. During long term testing specific biomass consumption was found to be decreased from 3.9 to 1.7 kg/kWh at different loading conditions. Biomass was characterized by conducting Thermo gravimetric analysis (TGA). Thermo gram of *Leucaena leucocephala* and *Prosopis juliflora* are found better for getting sufficient amount of tar in case of gasification of this material. The quantum of lighter volatile for *Leucaena leucocephala* (Subabool), and *Prosopis juliflora* ranged from 55 and 52 per cent, respectively. Heavier volatile for *Leucaena leucocephala* (Subabool) and *Prosopis juliflora* during gasification range from 15 and 17 per cent, respectively. However, on the basis of TGA analysis biomaterial can be gasified effectively.

Keywords: producer gas, woody biomass, pellets, gasification, pyrolysis, thermo- gravimetric analysis.

INTRODUCTION

The continuous growth of global energy consumption raises urgent problems related to energy availability, safe operation and its efficiency. The larger part of mineral oil and gas reserves energy supply is located within a small group of countries, forming a vulnerable energy supply. Moreover, this supply is expected to reach its limits. On the other side, the use of fossil fuels causes numerous environmental problems, such as local air pollution and greenhouse gases (GHGs) emission (Carlo *et al*., 2005). A possible way to deal with these problems is the development of cleaner and renewable energy sources. Modern use of biomass is an interesting option, because biomass is worldwide available, it can be used for power generation and biofuels production, and it may be produced and consumed on a CO_2-neutral basis (Hall *et al*., 1993; Rogner, 1999; Turkenburg, 2000). Biomass is used since millennia for meeting myriad human needs including energy. Main sources of biomass energy are trees, crops and animal waste. Until the middle of 19th century, biomass dominated the global energy supply with as seventy percent share (Grubler and Nakicenovic, 1988). Biomass gasification is the process of converting solid into combustible gases; it is a thermo-chemical process in which the fuel gas is formed due to the partial combustion of biomass (Tripathia *et al*., 1999; Pletka, 2001; Dasappa *et al*., 2003). This technology was developed around 1920 and played an important role in generating motives power till other fuels made their appearance (Rathore *et al*., 2007). The use of biomass as an energy source has high economic viability, large potential and various social and environmental benefits.

(Ravindranath, 2004). Inexpensive materials such as forest residue, wood residue, and rice straw are few potential feed stocks for biomass gasification. However, the cellulose, hemicelluloses and lignin composition of these materials may differ significantly (Minowa *et al*., 1998).

MATERIALS AND METHODS

A wood based gasifier engine system was procured and installed at Department of Un-conventional Energy Sources and Electrical Engineering, College of Agricultural Engineering, Dr. PDKV, Akola, M. S., India. The project was undertaken for testing and evaluate the performance of downdraft gasifier for power generation using different woody biomass.

Description of power plant

The biomass-based power plant is of 10 kW rated capacity and the system consists of a gasifier, water scrubber filters and gas engine coupled with AC Generator.

(i) Gasifier

The gasifier is downdraft type and the ash is removed through ash collection pit. The gasifier outlet is connected with ventury water scrubber. In a ventury negative pressure is created through which producer gas is supplied to burner for starting of gasifier.

(ii) Cooling and cleaning system

The gas produced from gasifier is passed through a cooling and cleaning system consisting of a ventury, one course filter, and one security filter. The gas coming out from the gasifier is cooled in a ventury scrubber. The cooled gases received after ventury scrubber was further sent through the fine filter. The fine filter is filled with sawdust in which the tar is further removed and the gas is sent to security filter. The security filter is fitted with fabric cloth. The gases are passed through fabric cloth to arrest the remaining dust particles present in the producer gas. The cleaned gases are supplied to SI Engine coupled with AC Generator.

Engine

The producer gas engine coupled with gasifier is spark ignition water cooled engine having 1500 RPM, 20 HP/12 kW, two cylinders. The carburetor has been fitted to regulate mixing of producer gas and air for smooth running of the engine at different load.

Gas engine: The gasifier efficiency was calculated by following formula,

$$\text{Gasifier efficiency } (n_g) = \frac{Hg \text{ X } Qg}{Hs \text{ X } Ms} \text{ x } 100$$

Where,

Hg = Heating value of gas, kJ/ m^3
Qg = Volume flow of gas, m^3/s
Hs = Heating value of solid fuel, kJ/ kg
Ms = Gasifier solid fuel consumption, kg/s

AC generator

The AC Generator is of three phase operating at 1500 rated rpm, 415 V, 3 Phase. The rating of AC generator is 15 kVA at 50 Hz. The generator has self-regulated exciter including battery charger DC output at 12 V.

Fuel

The biomass used for testing the gasifier is firewood chips of *Prosopis juliflora*, *Leucaena leucocephala* and pellets prepared from agricultural residue such as ground nut shell of approx. size of 25 x 20 x 25 mm^3 having moisture content 12-14 per cent. Fuel properties of various fuels used in gasifier is summarized in Table-1.

Table-1. Mean value of physical and thermal properties of biomass fuel.

Fuel	GSP	LL	PJ
Length, mm	25	24.9	24.7
Diameter, mm	20	25	25
Moisture content (wb) %	9.2	8.4	8.6
Bulk density, g/cc	1.1	0.364	0.407
Tumbler resistance, %	96.63	-	-
Shatter resistance, %	98.03	-	-
Resistance to water penetration, %	85.84	-	-
Volatile matter, %	64.87	82.17	83.05
Ash content, %	7.54	1.47	1.7
Fixed carbon, %	15.78	16.94	15.94
Calorific value, kcal/kg	4123.15	479.35	4856.45

Where
GSP = Groundnut shell pellet,
LL = *Leucaena leucocephala* (Subabool),
PJ = *Prosopis juliflora* (Vilaytee babool)

(a) Thermo gravimetric analysis

Thermo gravimetric analyzer is used for determination of gasification related properties of biomass such as volatile, fixed carbon and ash content. Thermo gravimetric Analysis or TGA is a type of testing that is performed on samples to determine changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, time and temperature range. TGA is commonly employed in research and testing to determine characteristics of material such as polymers, to determine degradation temperatures, absorbed moisture content of materials, the level of inorganic and organic compounds in material, decomposition points of explosives and solvent residues.

The analyzer usually consists of a high-precision balance with a pan (generally platinum) loaded with the sample of *Leucaena leucocephala* (Subabool), *Prosopis julilflora* (Vilaytee babool) and groundnut shell pellets weighted 0.25 g, each. The pan is placed in a small electrically heated oven with a thermocouple to accurately measure the temperature. The atmosphere may be purged with an inert gas to prevent oxidation or other undesired reactions. A computer is used to control the instrument. Thermo gravimetric analysis of the biomass samples were carried out at Power and Energy Division, Central Institute of Agricultural Engineering, Bhopal (M.P.).

TGA of *Leucaena leucocephala* (Subabool) wood

Leucaena leucocephala (Subabool) wood material was used for TG Analysis. Typical thermo gram is given in Figures 2 and 3 showed four distinct segments. The moisture removal last up to 240^{0}C for which 15 min. was required. The release of lighter volatile initiated in the range of 240^{0}C and continued up to 400^{0}C. The lighter volatile were noticed in the range of 55%. Heavier volatile range from 400-610^{0}C. It took 62 min for total devolatization. The lignin decomposition initiated at about 610^{0}C and last up to 830^{0}C. The oxidation temperature of biomaterial which is measure of thermal stability of biomaterial is found to be 385^{0}C.

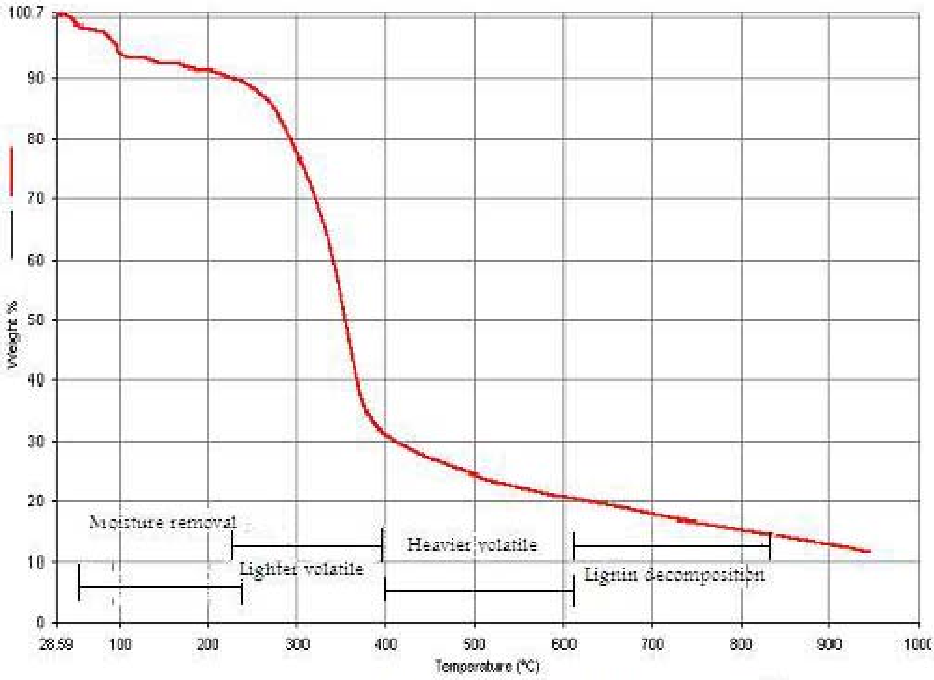

Fig 2. Thermo gram of Subabool at a rate of 10 ^{0}C/min

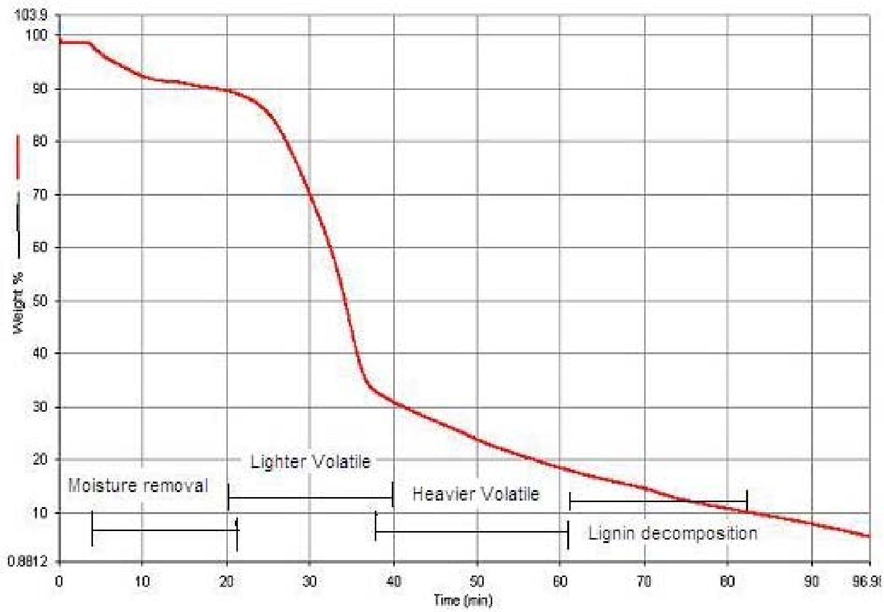

Fig. 3 Loss in weight with respect to time for Subabool at HR 10 ^{0}C/min

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TGA of *prosopis juliflora* (Vilaytee babool)

The typical thermo gram for Prosopis juliflora are given in Figures 4 and 5 which showed four distinct segment. The moisture removal last for 250^{0}C which took 22 min. In this material release of lighter volatile initiated at 250^{0}C and last up to 380^{0}C. The lighter volatile were noticed in the range of 50%. After release of lighter volatile, release of heavier volatile start at 380^{0}C and continued up to 590^{0}C.Oxidation temperature of *Prosopis juliflora* is found to be 390^{0}C.

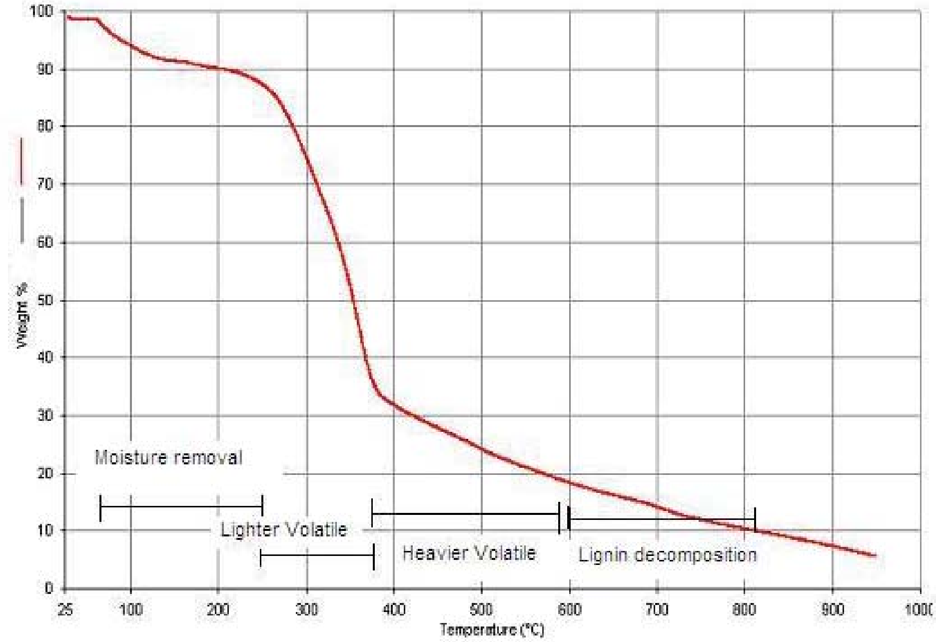

Fig 4.Thermo gram of prosopis Juliflora at a rate of 10 ^{0}C/min

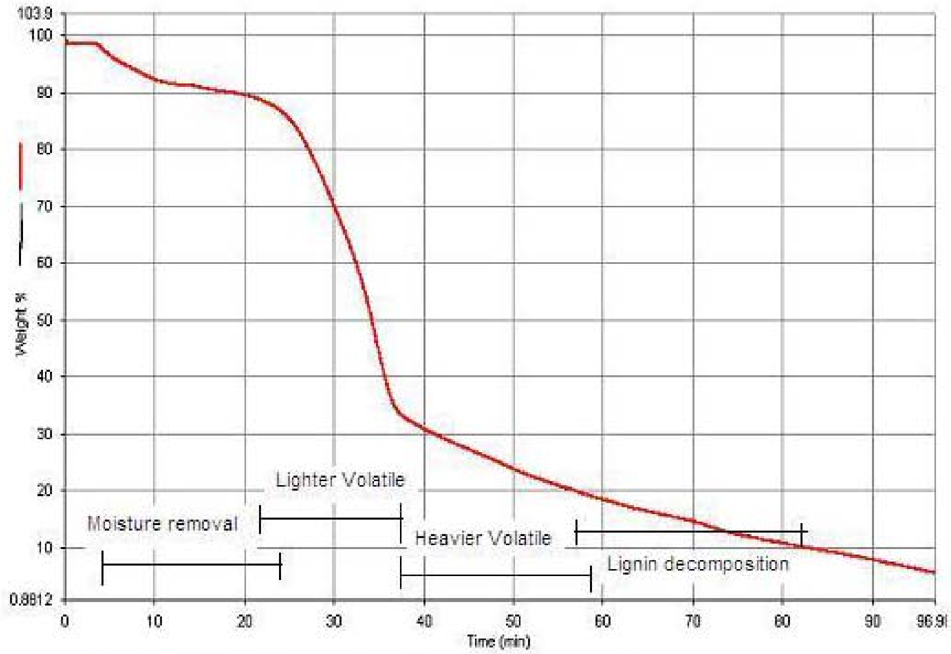

Fig. 5 Loss in weight with respect to time for Prosopis Juliflora at HR 10 ^{0}C/min

Groundnut shell pellet

Groundnut shell pellet was grinded in powdery form and then use for TGA. The typical thermo gram is given in Figures 6 and 7 showing four distinct segments. In this moisture removal last for 220^0C. The lighter volatile release initiated at 220^0C and continued up to 380^0C. The lighter volatile were in the range of 44 per cent. The heavier volatile release initiated at 380^0C and last about 600^0C. The lignin started to decompose at 600^0C and continued up to 760^0C.

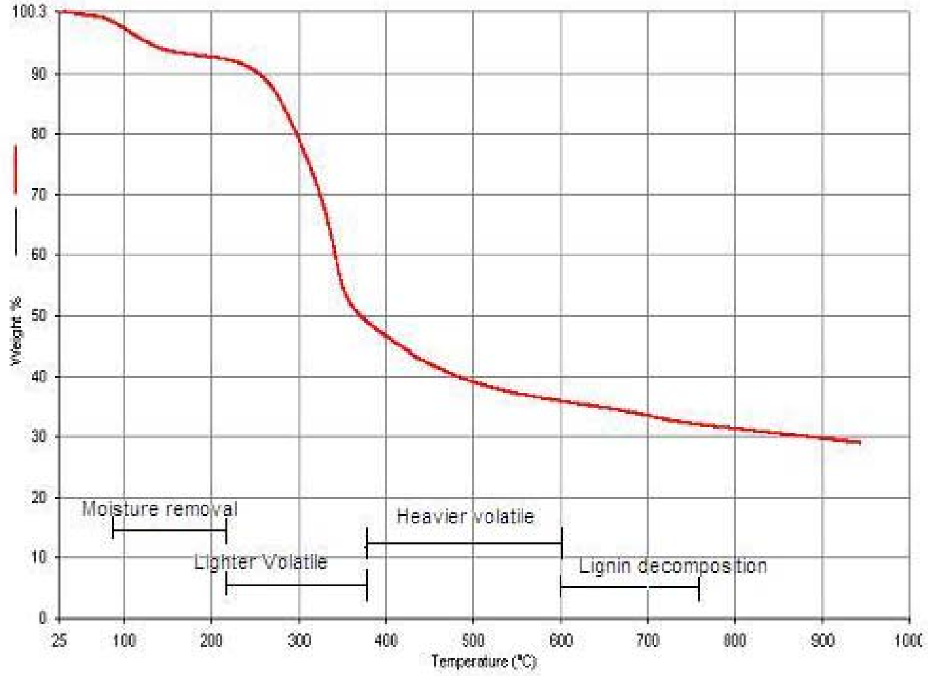

Fig 6. Thermo gram of GS pallet at a rate of 10^0C/min

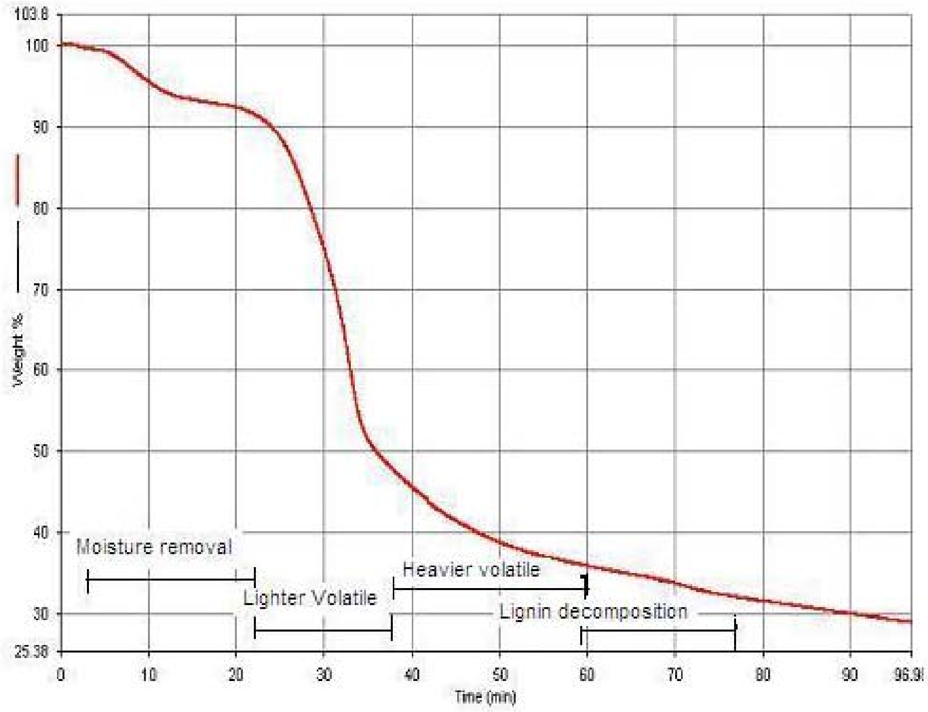

Fig. 7 Loss in weight with respect to time for Groundnut shell pallet at HR 10^0C/min

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(b) Loading device

The resistive loading device of 10 kW capacities was developed.

(c) Power measurement

The energy meter was used to measure the current, voltage, frequency and power factor of the output of AC generator coupled with the producer gas engine.

(d) Measurement of tar

The tar samples were collected in copper tube condenser dipped in ice bath. The length of the condenser is 5.0 m long. The temperature water bath in which condenser placed was maintained to be 5 ± 1 ^{0}C to cool the gases passing through condenser.

(e) Gasifier

The performance of gasifier was monitored at different engine loading. The producer gas temperature at exit from the gasifier varied from 217 to 318^{0}C. The tar content at the outlet of gasifier was 200 mg/Nm^3 and whereas after the cleaning unit tar was 10 mg/Nm^3. The biomass consumption at different load varied from 9.0 to 15.0 kg/h. The variation of biomass consumption and pressure drop at different filter are shown in Figures 8 and 9, respectively. The pressure drop in the fine and fabric filters was not changed significantly with the hours of operation. However, the pressure drop at fine filter touched 30 mm of water column, at that stage stir whole filter media, level it and observe the pressure drop.

The producer gas engine generator coupled with 3-phase alternator was evaluated at different loadings. The plant was continuously run for more than 8 hours in a day, current and frequency variation at different loading were shown in Figure-10. Quality of electricity generation from power plant was assured at different loadings. The frequency remains within allowable range i.e., 50 ± 1 Hz. Voltage ranged as 420 ± 10 V. The gas engine has found to respond well to load change as high as 9 kW. The performance of engine generator above 9 kW load is not responsive to change in load and frequency drops down to as low as 45 Hz. The overall system efficiency of generating the electricity from biomass was 16.3 per cent at maximum power.

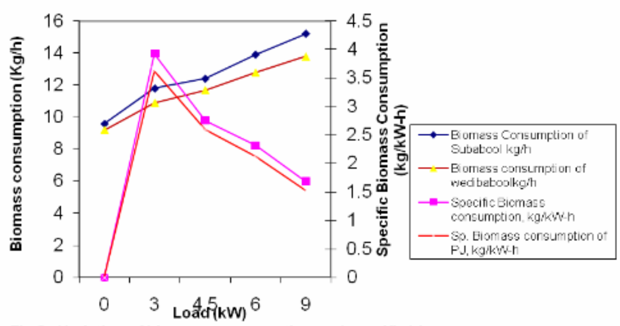
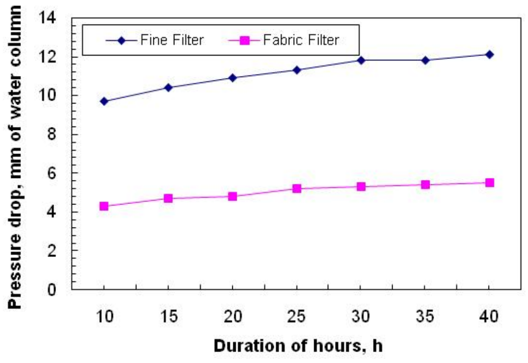


Fig 8. Variation of biomass consumption and specific biomass consumption with respect to load



Fif. 9 Variation of pressure drop at different filters

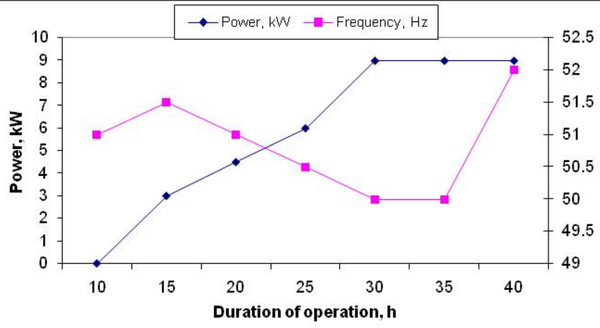


Fig.10 Variation of power & frequency with time

Integration of power plant with utility

The power plant generating the power was integrated with wood cutter used for cutting the biomass and departmental laboratory. The wood cutter was run with power plants for more than 20 hours of operation. No major problem was noticed in operation of wood cutter.

CONCLUSIONS

Biomass based power generation having power rating of 10 kW was installed and the performance of the system was evaluated. The specific biomass consumption was found to be decreased from 3.9 to 1.7 kg/kWh at different loading conditions. Thermo gram of *Leucaena leucocephala* (Subabool) and *Prosopis juliflora* (Vilaytee babool) are found better for getting sufficient amount of tar in case of gasification of this material. The quantum of lighter volatile for *Leucaena leucocephala*, and *Prosopis juliflora* ranges from 55 and 52 per cent, respectively. Heavier volatile for *Leucaena leucocephala* and *Prosopis juliflora* during gasification range from 15 and 17 per cent, respectively. However, on the basis of TGA analysis biomaterial can be gasified effectively.

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