Case Studies on Small Scale Biomass Gasifier Based Decentralized Energy Generation Systems

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Abstract

The growth of the economy is directly linked to the availability of quality power. As per the estimates of the Ministry of Power, Government of India [1], there is a power deficit to an extent of 8% in the country. It is planned to mitigate this shortfall by increasing the share of contribution of renewable sources in the energy portfolio. Renewable energy is also intended to be used in decentralized power generation systems in order to mitigate the power crises in the rural areas. This concept of decentralized power generation and distribution has been successfully demonstrated in two villages of India based on Indian Institute of Science (IISc) biomass gasification technology. One of them is a demonstration plant which had operated for more than 15 years in an un-electrified village named Hosahalli in Tumkur district, Karnataka. The other plant is related to the recently installed plant at Kasai village in Madhya Pradesh under the Village Energy Security Program (VESP) of the Ministry for New and Renewable Sources (MNRE), Govt. of India. These two are presented as case studies in this paper along with the 5 kWe demonstration model working at the Mahatma Gandhi Institute of Rural Energy and Development (MGRIRED).

1.0 Introduction

It is a well established fact that access to quality, reliable and affordable energy is critical for promoting economic and social development in rural areas. The energy situation in rural India is characterized by low quality of fuels, low efficiency of use, low reliability of electricity supply and access, leading to lower productivity from the use of land, water and human effort resulting in low quality of life and environmental degradation [2]. As per the Ministry of Power (MOP), Govt. of India [1] estimates, about 8% power deficit is prevalent in the country. This has strained the availability of power in rural areas. On the rural electrification front, the Ministry estimates that 74% of villages are electrified with still 154,230 villages remaining un-electrified. Of these around 18,000 villages have difficulty in linking with the grid and hence to be electrified by a decentralized source of energy. Even in the so called grid linked villages the quality and availability of power is poor. In order to mitigate the power crises, MOP has launched an ambitious program called "Power for all" by 2012. The underlying approach of this program is to strengthen power generation in the country by utilizing locally available resources in a sustainable manner. Another in-built strategy of decentralized power generation is the reduction of transmission and distribution losses. This therefore opens up a huge potential for small scale distributed power generation systems. There is a realization of the need to search for decentralized and renewable energy based options to meet the rural energy needs in a sustainable way [2, 3, 4]. Among the renewables, bioenergy technologies are being explored for meeting rural electricity needs. One such technology is biomass gasification which effectively utilizes locally available bio-resources such as forest residue, agricultural residue etc and converts them into a clean gas that could be utilized in dual-fuel or gas engines for power generation. Apart from improving the quality of rural life in terms of providing illumination, drinking water and irrigation, this technology also provides opportunity for the creation of micro enterprises that would enhance rural employment and thereof the rural economy. This technology also promotes sustainability and does not contribute towards net CO_2 addition to the atmosphere.

In gasification technology, the solid bio-residue is converted to gaseous fuel by thermo-chemical conversion which is further conditioned and made suitable to operate in an engine. Gasification involves partial combustion of biomass under controlled air supply, leading to the generation of producer gas constituting of combustible gases H_2 (20 %,) CO (20 %), CH_4 (1 - 2% and rest inerts). The energy value of producer gas is about 5.0 MJ/m^3. Development of the gasifier at IISc and other aspects of fuelling internal combustion engines are well published in literature [5, 6, 7]. Power generation through an engine is possible by substituting diesel in a diesel engine to the tune of 80% or by using a spark ignited gas engine

2.0 Case studies

This paper consolidates case studies of three small-scale power generation units, two of which are meant for rural electrification and the other as a demonstration unit at a training center. The paper presents the technical performance and the services provided in these projects. Plant management, social aspects and the impact of its technology on Hosahalli village can be referred from the literature [8, 9].

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2.1 Hosahalli Village Gasifier

Hosahalli is the first un-electrified village in the country to be served by a biomass gasifier in terms of quality supply of electricity. The village is located at 100 km from Bangalore in Tumkur District, Karnataka. It has about 35 houses with agriculture being the main occupation of the people. Hosahalli didn't have any agricultural pumps sets or a flourmill. Kerosene was used in traditional wick lamps for lighting. Women carried water from a polluted open water tank nearly 1 km away from the village. Farmers depended on rainfed agriculture, and were subjected to the vagaries of monsoon and low crop yields.

They occasionally hired diesel engines for pumping water for irrigation. The bio-energy project was planned and implemented by the Centre for Sustainable Technology (CST), Indian Institute of Science (IISc) in the year 1988. The project was planned by holding discussions and meetings with the Hosahalli village communities explaining the roles, responsibilities, benefits and the need for their participation. A role was created for the village committee to participate and help in raising and protecting an energy forest in about 2.5 hectare of land. Mixed species forestry concept was adopted, the species planted include: Acacia auriculiformis (13 %), Eucalyptus (58 %), Dalbergia sisso (7 %), Casia siamea (22 %). Fast growing and coppicing species were preferred and most of the species were also legumes, which fix Nitrogen to enrich the soil. A productivity of 6 t/ha/yr was reported during the initial years when detailed measurements of productivity were made [8, 9]. Details about the Hosahalli plant can be found in the publication [8].

A 3.75 kWe biomass gasification coupled to a diesel engine was installed in the year 1988 and the local youth were trained to operate and undertake minor maintenance of the systems. The village committee managed the systems, taking decisions on operation of the units, supervision of the operator, protection of the forest and ensuring repayment for the services. The biomass feedstock in the initial years came from social forestry plantations in the nearby villages. The investment for creating the entire infrastructure such as installing power generation, distribution and enduse systems (lighting, irrigation water pumps, flour mill, gasifiers, diesel engine generator, building, etc) and raising the energy forest was provided by CST from project funds from several funding sources under different projects.

The gasifier was operated only in the evening hours to provide home lighting and drinking water requirement. The women of the village appreciated the services as it reduced their burden of fetching drinking water from an open tank from a distance of 1 km. The quality of the drinking water was also better as the project provided water from a deep bore well. This system no doubt got social acceptance but did not change the quality of life as anticipated. The gap that prevailed between perception and reality was that the power generation system did not aid in any income generation activity. Towards this end the system configuration was enhanced to 20 kWe and power was provided for irrigation.

Table 1: Details of Hosahalli Energy Center

Description	Hosahalli
Size of village(No of hh)	35
Population	218
Energy plantation (ha)	4
Installed Capacity (kWe)	20.0
Installed end use capacity	
• Lights	4.0
• Drinking water	2.6
• Flour mill	5.6
• Irrigation pumps	18.5
Total installed end use capacity	30.7

Year of establishment	1988
Institution planning & implementation	ASTRA & GVS

The 20 kWe power package consisted of a gasification system and a diesel engine. The gasification system in turn consisted of a reactor, cooling and cleaning system and flare to check the gas quality during start-up. Since there was no other form of electricity available in the village, the diesel engine had to be initially operated to start the gasification system and once gas generation was ensured by flaring the gas in the burner, the gas was supplied to the engine and operated in dual fuel mode (producer gas + diesel). After about 10 minutes the system got stabilized and the electric switch gear was energized to supply electricity to the entire village.

Plate 1: 20 kWe Biomass Gasification System at Hosahalli, Karnataka

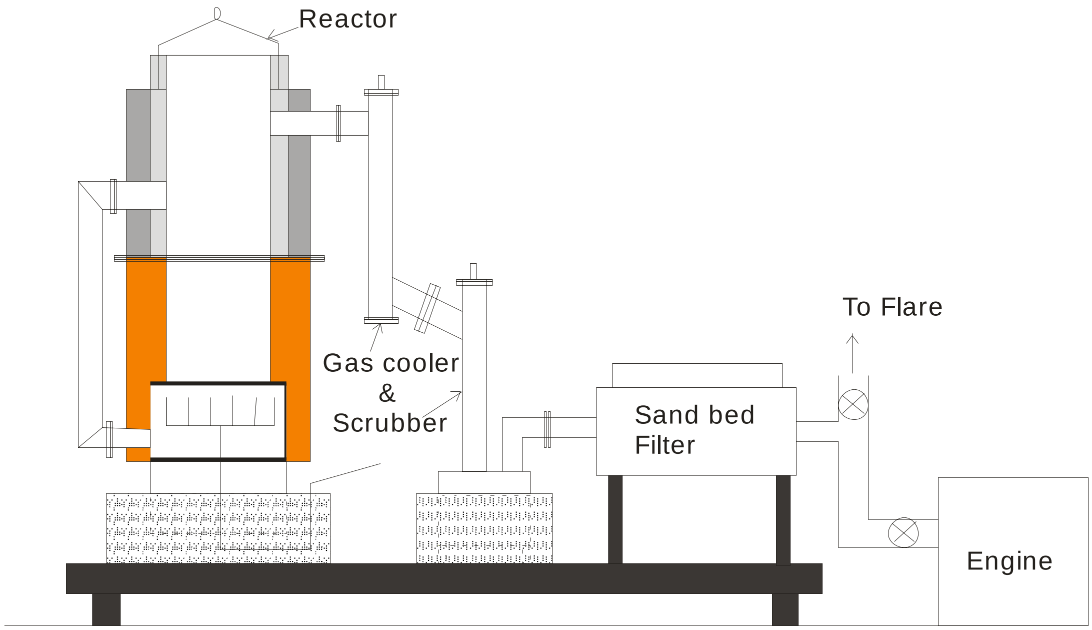

Fig. 1: Schematic representation of the gasifier

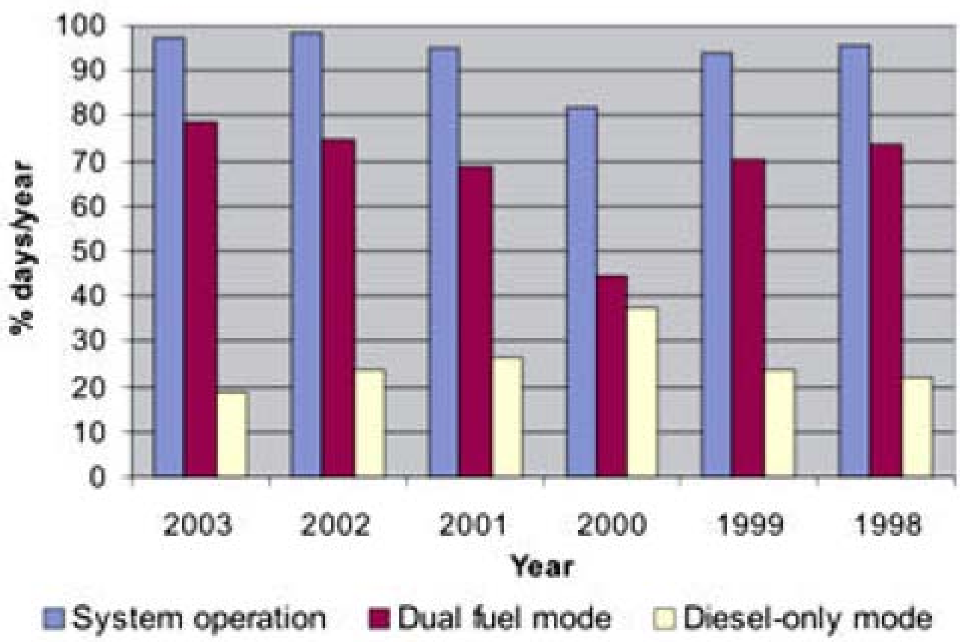

Fig 2: Performance of Hosahalli Gasifier

Summarizing the plant performance as shown in fig.2 for a 5-year time period between 1998 and 2003, the availability of power generation system was in excess of 90%, except during the year 2000 due to major maintenance in the gasification and engine system. Of this 90% availability, the dual fuel mode supported by biomass gasifier unit was operational for over 70% of the time. In the remaining time power generation was through diesel mode and this was due to various factors such as non-availability of dry biomass, gasifier maintenance or absence of operating personnel. The details of the system operation are shown in Table 2. The load profile improved over time wherein the number of units generated almost doubled with the introduction of irrigational facilities. The load stabilization also improved the diesel substitution to as high as 87%.The improvement in average annual diesel substitution from 54 to 87% was also due to better practice in terms of operation of the system.

Table 2: Details of system operations

Description	2003	2002	2001	2000	1999	1998
Electricity generated kWh/yr in dual fuel mode	18651	17185	12775	7238	9617	9300
Electricity generated kWh/yr in diesel alone mode	3326	3992	3476	5251	3276	2723
Total Electricity generated kWh/yr	21977	21557	16251	12489	12884	12023
Average wood consumption rate kg/kWh in dual fuel mode	1.8	1.64	2.07	1.28	1.27	1.32
Percentage Diesel substitution in dual fuel mode	86	87	81	81	54	58

In terms of providing of services to the Hosahalli village,, lighting was provided for over 80% of the days in most years. Piped water supply was also provided for over 80% of the days in all the years and over 90% of the days during 2001- 2003. A flourmill was operated twice or thrice a week depending on the demand for milling of grains. The irrigation system was operated depending on the crops grown, area irrigated, cropping season and demand from farmers. Thus the percentage of days when irrigation water was provided is low.

Thus, the basic services critical for determining the quality of life such as home and street lighting and piped water supply was provided on most days, again a unique achievement for a village in India. The cost of power generation in dual fuel mode varied from Rs 3.00 to Rs 6.00 per unit depending on the load on the system and the cost of diesel, which varied with time. For electricity generation to be competitive with grid, the only approach is to adapt a 100% gas engine in place of the dual-fuel mode. Lack of co-operation from the village to address the issue related to the increased cost, hence sustaining the plant operation became very difficult even though there were no technical issues. Therefore the plant operations have been stalled subsequent to the year 2004. Subsequent to the halt of this project, a grid line has been extended to the village. Even though the grid has arrived to the village, however, it is unable to ensure the same quality of power that was available through the decentralized power system.

2.2 Kasai Village Gasifier

Under the Village Energy Security Program (VESP) the Ministry of New and Renewable Energy Sources (MNRE), Govt. of India has a mandate of addressing the complete energy requirements of un-electrified villages in the states of Madhya Pradesh, West Bengal and Uttaranchal. Since the beneficiaries under this program were the forest fringe villages, the program is rightly implemented and monitored by the District Forest Officials (DFOs). This program addresses the complete energy requirement of a village, which includes fuel efficient stoves, biogas, biodiesel and biomass gasification system for electricity generation. Under this program, eleven forest fringe un-electrified villages in the state of Madhya Pradesh have been identified. The first among these villages to have benefited from this program is Kasai, which is located in Betul district [10]. This village is located far away from the district center and is not easily accessible by road. The village has about 55 households with a population of 392. The villagers are mostly tribals and agriculture is their main economic activity. Under this project, grid lines were laid in order to supply electricity to the house holds. The electricity is generated in the 2 x 9 kWe gasification plant installed under this project. The plant is also equipped with a small capacity diesel generating set for black start purpose. The uniqueness of this power plant is that electricity is generated using a producer gas engine, which has been specially developed for this purpose. The power plant consists of a gasifier reactor with screw based ash extraction system, cyclone, cooling and scrubbing systems, sand bed and fabric filter. The gas engine is a modified from a three cylinder diesel frame engine with necessary accessories such as gas carburetor, ignition system and an electronic governor to function as a spark ignited engine. The complete package is supplied by M/S Aruna Electrical Works, Villupuram (One of the Technology Holder's of IISc). To make the power plant sustainable, the forest department has planted a 10 hectare energy plantation. Currently the day-to-day plant operation is managed by the village panchayat. Currently the services being met are home illumination, street lighting and supply of drinking water. A flourmill has been energized and a water pump and milk-chilling unit are also proposed. A few households have started using music systems and colour televisions. An expeller unit is proposed to be installed to extract oil from the Jatropha oilseeds, which will be used for operating pump sets. Improved chulhas have been constructed in every house to conserve firewood and biogas plants are being setup to meet cooking energy needs of households [9].

The plant operates daily in the evening hours for supplying power to the village. The system operates for 5 hours in a day and on an average generates 40 units per day and 1200 units per month. The operation and maintenance of the plant is done by the local youth who have been trained in this aspect. The details of the Kasai energy center are given in Table 4. As a startup process, a diesel engine is used to operate the gasification system before switching the operations to gas alone mode. During this period the amount of diesel used depends upon the operator's care. It is amounting to about Rs. 0.4 per kWh which can be reduced to about Rs. 0.2 per kWh. Further, the cost of labour is about Rs. 2.5 per kWh. This has provided an opportunity to local employment. As indicated in Table 3, currently the cost of electricity generation is about Rs 3.79; however there is ample scope for cost reduction with the increase of usage through introduction of water supply for irrigation, power supply for bio-diesel production and other micro enterprises. The system has been in operation for over 10 months and the overall performance is satisfactory. During this period, a few operational issues and the logistics of establishing and using local operational skills were addressed.

Table 3: Energy Cost Details of Kasai Energy Center

Sl. No	Description	Cost in Rs
1	Cost of Biomass/kg	0.5
2	Contribution per family for electricity usage (Rs 120 per month per family)	6600
3	Cost of labour (Rs 1000 x 3)	3000
4	Cost of Diesel and oil per month (for black start only)	500
5	Total operational cost per month	4550
6	Unit power generation cost	3.79

2 x 10 kWe Gasifier System at Kasai

Home Lighting at Kasai

Plate 2: Biomass Energy System Installed under VESP [Village energy security program] of MNES at KASAI Village, Bethul Dist. MP

2.3 MGRIRED gasifier

Mahatma Gandhi Institute of Rural Energy and Development (MGRIRED) is a training center under the Rural Development and Panchayat Raj (RDPR) ministry. MGRIRED has a mandate of training and awareness creation for various players in appropriate rural energy technologies. The institute offers a residential training course for various target groups which include policy makers, consultants, village panchayat board members and rural youth. The institute has installed various renewable energy technologies for demonstration purpose. One among this is a 5 kWe rating open top biomass gasifier (IISc design) coupled to a standard diesel engine, which is operated in dual fuel mode (~ 70% gas + 30% diesel). The installed gasifier, meant for woody biomass, consists of a reactor with a bottom grate, scrubber cum cooler and a sand filter prior to supplying the generated gas to the diesel engine. The generated electricity is currently utilized for electrifying the administrative block of the institute during the office working hours (10 am to 5 pm). This unit was initially operated for a duration of nine months (February to October 2006) by CGPL, IISc, the details of which are summarized in the following paragraphs. Currently, the plant is being operated and maintained by the trained MGRIRED staff.

The plant was operated for 6 – 8 hours (February to October 2006) on a working day depending on the requirement of the institute. The off take of electricity by the administrative building was low, consisting mainly of lighting and fan load with average energy consumption being 0.8 – 1 kWh and occasionally the operation of a water pump and a photocopying machine, which resulted in higher loads. During this period, attempts have been made to increase the load on the engine as this would have an implication on the energy cost. The summary of operations in this period is given in Table 4.

Table 4: Operational summary of gasifier at MGRIRED

Month	No of Days	Office working hours	Gasifier hours	Availability, %	Useful kWh
February	20	154	136	88	NA
March	19	175	111	63	NA
April	18	154	108	70	NA
May	20	175	127	73	181
June	20	175	131	75	210
July	23	168	143	85	211
August	14	168	75	45	141
September	9	154	49	32	65
October	18	140	135	96	188

NA: Not Available, the energy meter was installed only in May 2006

It is evident from the above table that the gasification system availability was high except in the months of August and September, when the diesel engine was under maintenance.

It must be mentioned here that small capacity engines have an issue related to sub component reliability. Some of the issues that were addressed over here and also at Hosahalli are related to the frequent maintenance of the radiator, belt failure, failure of coupling between engine alternator, oil leakage etc. During this operation, the diesel replacement averaged in excess of 70% on most of the days as shown in Fig. 3, with highest and lowest replacement being 85% and 48% respectively. The only reason that can be attributed to this fluctuation is the continuously varying and low load on the engine (for instance operation of photocopying machine). Similarly the specific biomass consumption on daily basis between the months of July and September 2006 shows fluctuation as shown in Fig 4. The specific biomass consumption varied between 1.5 to 3.0 kg/kWh, the reason for it to be higher is due to part load operation (load of the engine was 1.0 kWe against the rated engine power output of 5 kWe).

The reason for high fuel consumption is related to low loads resulting in a lower conversion efficiency. The fuel consumption of engine operation with the base fuel – diesel is indicated in Fig 5, which shows the trace of specific fuel consumption (sfc) versus the load, and it is evident that the sfc at rated load is 280 g/kWh (around 320 mL/kWh or 3.1 units/lt) whereas the same at part load i.e. 25 - 30% (1.0 – 1.5 kW) is about 550 g/kWh (or 650 ml/unit or 1.5 units/lt), which corresponds to a low efficiency of about 12 to 13%. This is a typical characteristic of the engine. This is reflected on the biomass consumption, the specific biomass consumption being high in dual fuel mode is related to load being low (at rated load one can expect a specific biomass consumption of about 1 – 1.2 kg/kWh).

Even though the diesel replacement is around 70 % in the operational load range, the diesel requirement per kWh is in the range of 250 – 300 ml. The diesel cost component in the energy cost amounts to about Rs. 6 as against Rs. 25 in the diesel mode. The cost of diesel in the dual fuel mode accounts to about 80 % of the energy costs. Thus, cost of electricity generation with the power load being so low would definitely be higher, the only manner by which cost of electricity generation could be made meaningful is to operate the plant close to its rated capacity (~ 4 to 5 kWe).

Thus it is evident that there are three fold changes that need to be considered for economical operation of the gasification system:

1. Increase the load on the system
2. Change the diesel to bio-diesel, if available
3. Change to gas engine

With the change to gas engine, the diesel component would be totally eliminated from the energy costs. In the case of gas engine, low loads imply a slightly increase in biomass consumption and the cost of energy is not seriously affected, as it depends upon the cost of biomass. This aspect provides the necessary incentive for the promotion of the modern biomass gasification technology package.

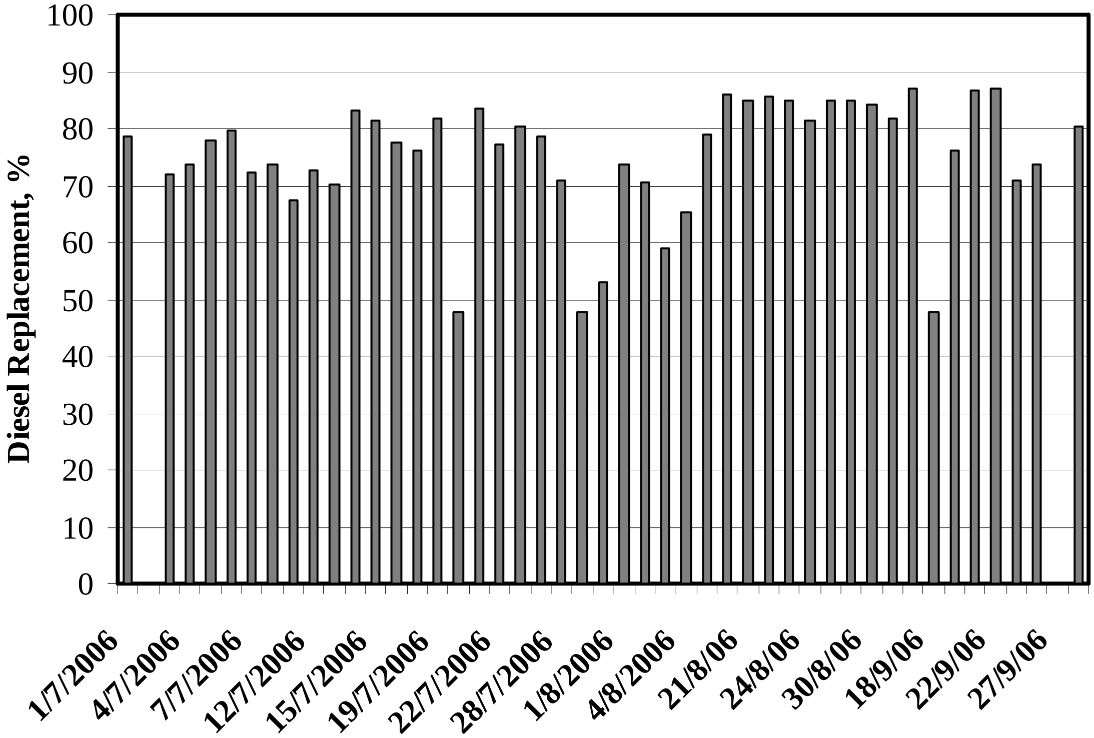

Fig. 3: Diesel Replacement against various days between July and September 2006

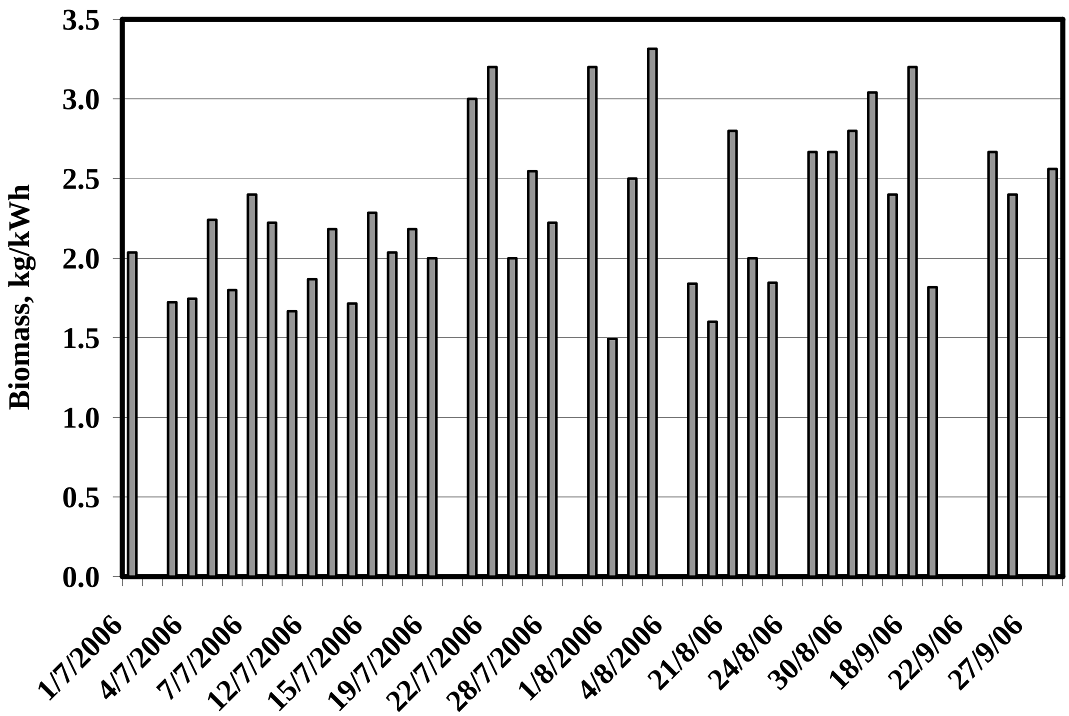

Fig. 4: Specific Biomass Consumption against various days between July and August 2006

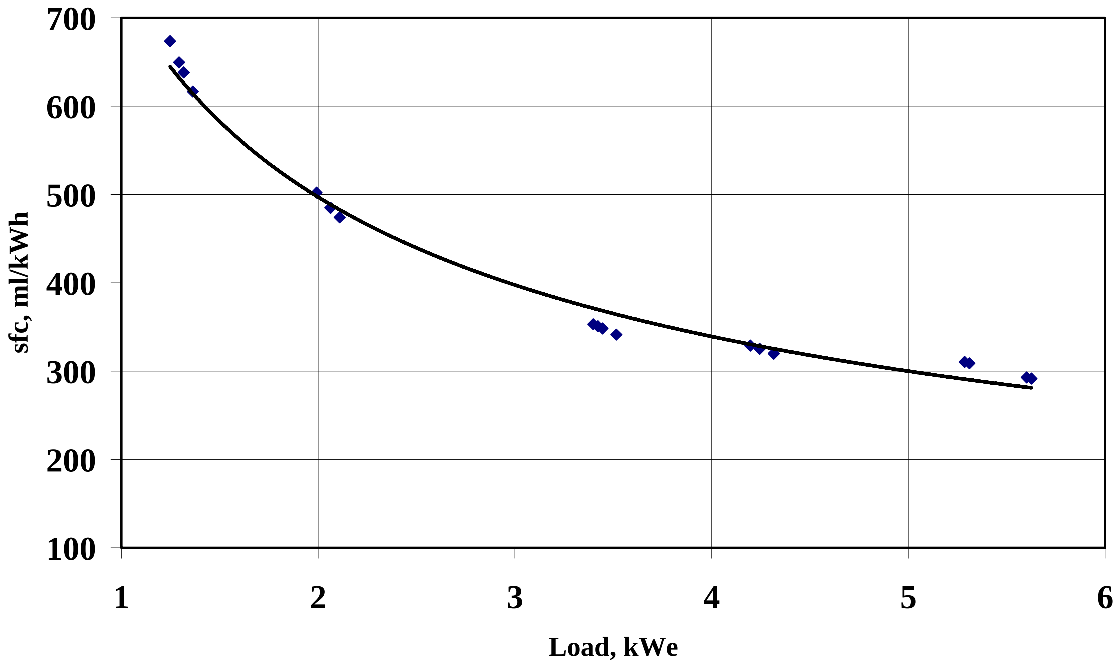

Fig. 5: Specific Fuel Consumption against Load in Diesel Mode

3.0 Conclusion

The case studies bring out the following message:

1. Biomass gasification technology holds large promise as a decentralized power generation system in terms of improving the quality of life, which includes supply of quality electricity on demand for illumination, supply of hygienic drinking water, irrigation and possibility for rural micro enterprises.

2. This technology can be sustained using local available resources such as fuel and manpower for day-to-day operation of the plant.

3. The Hosahalli village case study has shown that there are not many technology ridden problems with high plant availability.

4. Gasifier coupled with gas engine generator set is more economically viable compared to diesel generator set. For dual fuel operations to become attractive, we have to use locally generated bio-diesel in place of expensive diesel. Also, the plant needs to be operated close to rated capacity to derive the best in terms of efficiency and cost of power generation.

5. The technology package being conceived for remote village electrification must encompass a suitable system for black start purpose. Also, the technology package should encompass sub-components that are easily maintainable by the trained local operators.

From the above case studies, an important learning is that even at small capacities, by using gas engines, a sustained economical operation is possible, as the major operational cost are related to biomass cost. In this case, it is important to address the sustained availability of biomass locally, thus reducing the dependence on fossil fuel, an important concept for distributed power generation packages for the rural sector.

4.0 Acknowledgements

The authors wish to acknowledge Ministry of New and Renewable Energy (MNRE), who have funded the Kasai project in Madhya Pradesh and partly the Hosahalli project in Karnataka. Similarly the authors wish to thank Aruna Electrical Pvt Ltd, a Licensee of IISc technology for having shared data with respect to Kasai installation. The authors also wish to thank MGRIRED for having provided CGPL, IISc an opportunity for supplying and demonstrating the gasifier technology package at their institute.

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