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Development and Operational Experience with Topless Wood Gasifier Running a 3·75 kW Diesel Engine Pumpset

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ABSTRACT

Operational experience with a topless hybrid wood gasifier powering a 3·75 kW diesel engine pumpset is detailed. The gasifier–engine pumpset has logged 250 h of operation. The fuel was Leucaena leucocephala *wood from trees 1–2 years old. Average diesel substitution varied between 50–78% depending on load. With increased load the diesel substitution decreases. On average the gasifier consumes 1·33 kg of wood and 125 ml of diesel to produce 1 kWh of mechanical energy for water pumping. Economic analysis reveals that at 60% diesel substitution and wood cost of Rs 0·5/kg (1 US$ = Rs 13·0), the gasifier system is economically comparable to stand alone diesel water pumping systems. Reasons for slow propagation of this technology in rural areas are outlined.*

Key words: biomass gasification, economics, performance, rural areas, topless, wood gasifier, 3·75 kW diesel pumpset.

INTRODUCTION

Developing Countries use a substantial amount of energy for irrigation. In India alone about 23×10^{10} MJ/year is used in pumping water.[1] About 72% of this energy is for diesel pumpsets. These pumpsets are in the range of 3–5 kW. There are about 3 million diesel pumpsets operating in India. They consume about 3·75 million tonnes of diesel each year.[2] With shortfall in electricity production and subsequently in its distribution to rural areas, the dependence on diesel pumpsets for irrigation not only will continue but will also increase.

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Large consumption of diesel in pumpsets also puts a heavy drain on the foreign exchange of Developing Countries. Additionally, its rising cost and periodic nonavailability in rural areas creates inconveniences for the farmers. One of the ways in which diesel for pumpsets can be saved is by use of producer gas in them.

Use of producer gas to power diesel (dual-fuel) and petrol engines is an old technology. During World War II there were close to 1 million engines running on producer gas all over the world.[3] However, the use of gas in small (3–5 kW) engines is of recent origin because of increased irrigation requirements in Developing Countries. Thus, an effort is underway in most of these countries to develop reliable gasifier powered pumpsets.

This paper therefore presents operational experiences of powering a 3·75 kW diesel pumpset by a topless hybrid gasifier. Details of the gasifier, operational parameters and economic analysis are presented.

MATERIALS AND METHODS

Gasifier set up

The gasifier powered diesel pumpset consists of: (a) gasifier, (b) cooling/cleaning train and (c) diesel engine/pumpset. Figure 1 is a schematic drawing of the system which is described in the following:

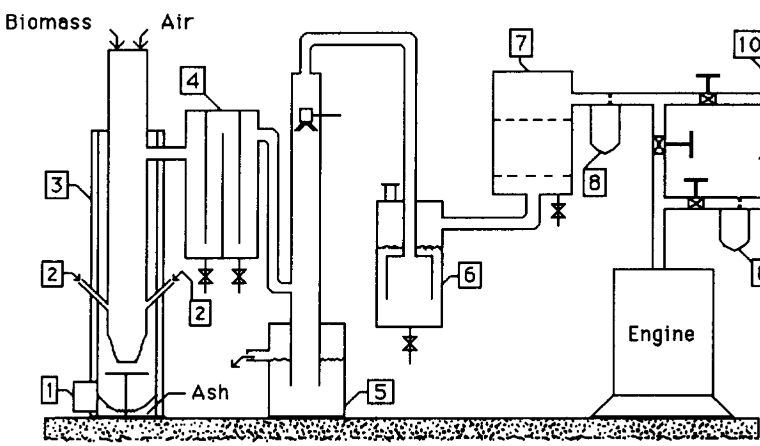

Fig. 1. Schematic diagram of the gasification system. 1, Ash door; 2, air intake; 3, gasifier; 4, dry filter; 5, wet scrubber; 6, bubble filter; 7, cotton filter; 8, orifice meter; 9, air filter; 10, blower.

Gasifier

Historically the gasifier work has been restricted to gasifiers with a throat.[4] With large systems, as were in vogue in World War II, and even of recent origin, this design has served the purposes well. However, for small power applications (3–5 kW) the narrowness of throat creates problems in biomass flow because of bridging. This problem can be solved by use of a throatless and topless gasifier. Its simplicity of design and fabrication also makes it a strong contender for small systems.

Consequently, various throatless and topless gasifiers were designed and experimented upon.[5] These were based on ideas of various investigators.[6,7,8] It was found that there was a tendency for the combustion zone to move up the tube since the biomass and air were entering from the top of the tube. This changed the bed characteristics and consequently the quality of the gas. To overcome this, two side nozzles were used from where 70–80% of the air entered the gasifier—the rest coming from the top. With this modification the present gasifier can be classified as a hybrid design. It is a cross between the throatless/topless design and conventional throat/top closed systems. In absence of any better name this gasifier has been designated a hybrid gasifier.

The gasifier used in the present study has a tube of 15 cm diameter and is 1·8 m long. The throat is of 8 cm diameter with two inlet nozzles of 1 cm each. The size of the nozzles and their location was calculated using design criteria developed for conventional throat gasifiers.[9] The construction material is mild steel of various gauges. The gasifier is intermittently shaken by vibrations from the engine which helps in smooth biomass flow.

Cooling/cleaning train

Various types of gas cooling/cleaning equipment were developed and tested. The one chosen consisted of a wet and dry scrubber (Fig. 1). In the dry cooler/cleaner, the tar and condensables were condensed. The gas then passed through a jet cleaner, a sieve plate foam cleaner and finally through a cotton filter. The pressure drop across the cleaning/cooling train was measured by manometers attached at various points in the line.

Engine

The engine pumpset was a 3·75 kW single cylinder diesel engine with 1500 rpm speed and 0·478 litre capacity. The compression ratio was 16·5 : 1 with specific fuel consumption of 252 g/kWh. The speed of the engine could be controlled by an external accelerator switch. No modifications to the engine were made for running in the dual-fuel mode. The gas and air were mixed in a T-joint and fed directly into the engine.

Gasifier fuel

The fuel was wood from *Leucaena leucocephala*. This is a leguminous fast growing tree species which is being popularised in India for energy plantation. Table 1 shows the characteristics of the wood used for the gasifier.

The 1–2-year-old trees gave the correct diameter (2·5 to 3·0 mm) for the wood. This helped in reducing the labour and energy cost in fuel processing.

The gasifier was sensitive to moisture content (MC) of the wood. With higher MC (over 15%) there was more tar production and reduction of gas calorific value.

Experimental procedures

The pressure drop across various cooler/cleaners was measured by calibrated manometers. The flow rate of the gas and the air to the engine was measured by calibrated orifice meters. The temperature of the bed was measured by Type K thermocouples. The calorific value of gas was measured by Junker's Calorimeter (Toshniwal Instruments, Madras) and its composition was determined by standard Orsat apparatus (Indian Scientific Instruments, Bombay). The calorific value of wood was determined by bomb calorimeter (International Scientific Co., Bombay). The load on the engine was varied by using a belt type prony brake and the shaft speed was measured by a hand-held tachometer (Toshniwal Instru-

TABLE 1
Characteristics of Wood Used in Gasifier

Tree species	*Leucaena leucocephala*; variety K8
Size of processed wood	2·5–3·0 cm ϕ and 4–6 cm long; hand cut; two labourers working 8 h/day can cut between 50–60 kg of wood
Tree age	1–2 years
Moisture content (MC)	Freshly cut wood 40–45%; wood of 7–15% MC used in gasifier
Calorific value of wood	17·6–18·4 MJ/kg (oven dry)
Wood density	700–720 kg/m^3 (Bulk density of 200–220 kg/m^3)
Ash content	1–2%
Frequency of wood loading in gasifier	60–80 min

ments, Madras). The tar and solid particle content of the gas entering the engine were measured by using a cotton plug in the inlet line. The initial and final weight of the cotton plug after oven drying, gave the amount of solid particulate content of the gas. The diesel consumption of the engine was measured by a graduated cylinder attached to the diesel inlet line. The diesel consumption was double checked by topping the graduated cylinder with a known quantity of diesel.

RESULTS

The results of the study are summarised in Table 2. As can be seen from this table, the solid particulate content was slighly higher than permissible for such dual-fuel engines.[4] This number could only be reduced by increasing either the number of cleaners or the efficiency of cleaning. Both these cures invariably increased the pressure drop in the gas line and ultimately reduced the diesel substitution. The next best thing was reducing the frequency of oil change from 250 h (manufacturer's recommendation) to 100 h. The oil quality before changing was established by the filter paper test.[10]

TABLE 2
Summary of the Results

1. Total operational time (gasifier–engine system)	250 h
2. Diesel substitution	50–78% (depending on the load, (Fig. 2))
3. Temperature of combustion/ reduction zone	800–1050°C
4. Average wood consumption	2·5–4·7 kg/h (Fig. 3 shows typical daily run data)
5. Average calorific value of gas	3·55–4·6 MJ/Nm^3
6. Composition of gas	5–14% CO; 16–26% H_2; 4–12% CO_2 and and 4–11% O_2
7. Specific fuel consumption	0·84–1·6 kg/kWh
8. Charcoal production	3–14% (w/w)
9. Tar production	5–15 g per kg of wood
10. Solid particulate content of gas reaching the engine	0·33–2·55 g/Nm^3
11. Cleaning frequency of filters	50–60 h
12. Lubrication oil change in engine	100 h
13. Average amount of fuel used in generating 1 kWhr of mechanical energy	1·33 kg wood + 125 ml of diesel

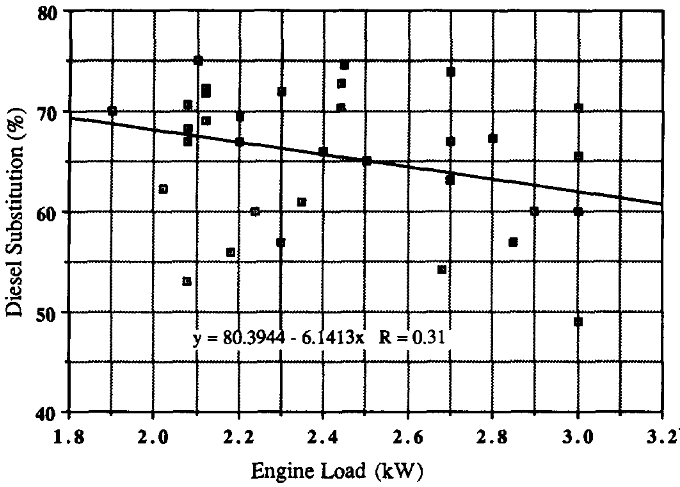

Fig. 2. Variation of diesel substitution with load.

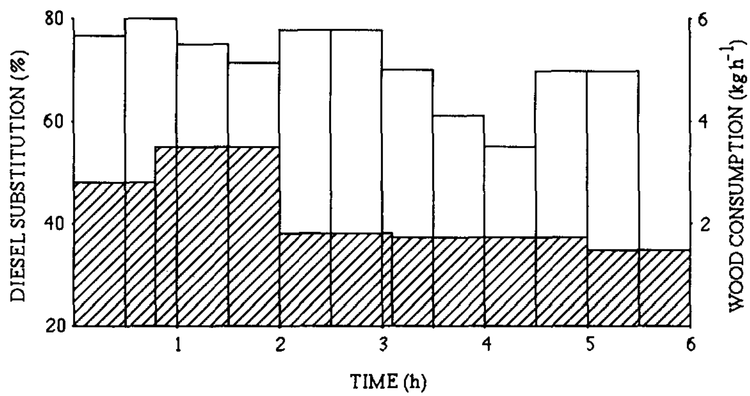

Fig. 3. Diesel substitution and wood consumption histograms. Engine load: 2·12 kW (58% of rated load). Average diesel substitution: 71·5%. Average wood consumption: 1·1 kg/kWh.

Another aspect of the gasifier was the low temperature of combustion/reduction zone. This obviously did not crack the tars properly and also increased the amount of charcoal production. The charcoal fines were mixed with cow-dung in a ratio of 4:1 and the resultant briquettes were found to be an excellent fuel for cooking stoves.

The cotton filters were saturated with dust and moisture after about 50 h of operation. This again increased the pressure drop and subsequently caused reduction in diesel substitution. Thus the cleaning schedule for the whole cleaning/cooling train was set between 50–60 h.

Assuming the pumpsets run 4 h per day a complete cleaning of system would be required about every two weeks. The cleaning of the train took approximately 1–2 man-hours.

ECONOMIC ANALYSIS

Economic sensitivity analysis of the gasifier system and its comparison with stand-alone diesel system for various diesel substitutions and costs of wood is shown in Table 3, along with the assumptions used in the analysis. Figure 4 shows the details of the analysis. At current diesel cost (Rs 3·75 per litre) and wood cost (Rs 0·5 per kg), the gasifier system

TABLE 3
Assumptions for Economic Analysis

1. Cost of gas generator and diesel pumpset	Rs 15 000.00 (1 US$ = Rs 13·0)
2. Interest	18% per year
3. Maintenance cost/year	10% of capital cost
4. Engine time	4 h/day @ 300 days/year
5. Diesel consumption	1·1 litre/h at 3·75 kW (full) load
6. Pumpset load	Full

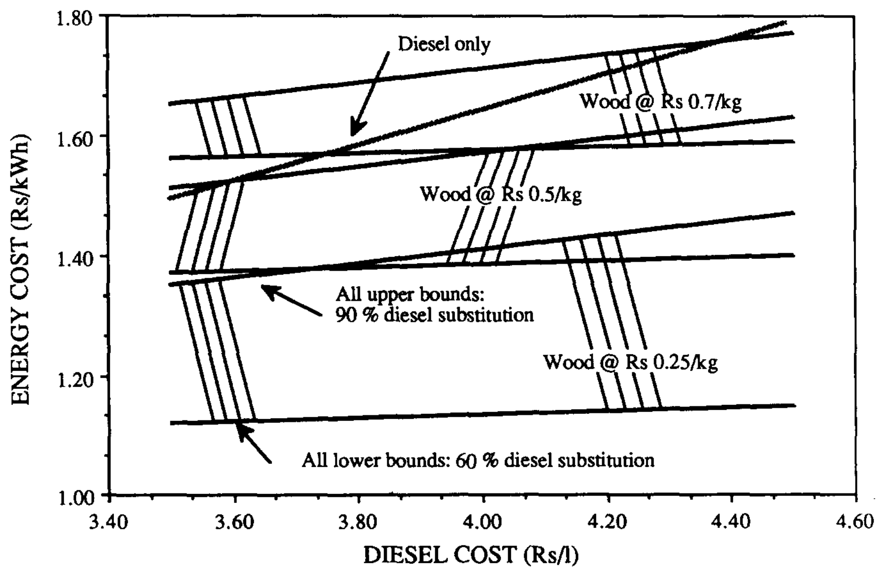

Fig. 4. Effect of amount of diesel fuel and cost of wood on energy output. Diesel only energy cost = 0·291 (diesel cost) + 0·4805.

operated at only 60% diesel substitution is economically viable as compared to only diesel fuel. It should be pointed out that at present the 3·75 kW gasifier *cum* diesel pumpset systems are selling in India at Rs 29 000.00 per unit. These systems are bought by Government of India and sold to farmers at the highly subsidised price of Rs 5 000.00 per unit. Such subsidies can only be used as means of propagating this technology and ultimately the systems have to be sold at economically competitive prices. Thus, the Rs 15 000.00 per unit cost used in our analysis is for large scale production scenario.

DISCUSSION

The topless hybrid gasifier has been very easy to operate and construct. The concept of fabricating a gasifier from a single tube and with easily available materials like mild steel is very attractive for rural areas where workshops are not equipped to handle stainless steel and complex shapes. That this gasifier is able to effect high diesel substitution attests to its advantages over conventional systems. With better insulation there are possibilities of less tar production. Efforts are underway in this direction.

Given that an excellent gasification system is developed, its ultimate users should be able to accept the technology. Discussions with farmers who will be the actual users of the small gasifiers for irrigation reveal the following bottlenecks for large scale propagation of this technology.

(1) Requirement of one trained person to be with the gasifier nearly all the time for proper monitoring of gas flow to the engine and biomass input in the gasifier. This is an additional burden on the farmer's income.
(2) Daily unpleasant chore of cleaning the tar laden water from coolers/cleaners.
(3) Change of lubricating oil at much more frequent interval than is normally done with diesel only fuel operation.
(4) High capital cost of the gasification system with unavailability of easy and soft term financing in rural areas.

The last point can easily be termed as the most severe bottleneck. In rural areas of India, progressive farmers buy tractors in large numbers. These tractors cost about Rs 1 250 000.00. These are bought because of easily available loans at easy credit from the banks. Similarly, though the gasifier system, even at today's diesel prices, makes economic sense, its large scale deployment is hampered because of unavailability of loans.

However, it is hoped that for any nascent technology propagation, such start-up problems that always exist will be solved in due course of time. As farmers find multiple uses for their gasifier systems, their initial resistance to new technology will also change.

CONCLUSIONS

Based on the present study the following conclusions can be drawn:

(1) Operational experience of topless hybrid wood gasifier powered diesel pumpset has been successfully gained. The system has logged about 250 h of operation.
(2) The gasifier diesel pumpset system required constant attendance of one trained person. Additionally, cleaning the system daily was slightly cumbersome to the operator.
(3) To produce 1 kWh of energy, 1·33 kg of wood and 125 ml of diesel were used.
(4) Economic analysis reveals that with a low (60%) diesel substitution and current diesel prices, the gasifier system is economically on a par with diesel-only fuel.
(5) Unavailability of easy financing for purchase of the gasifiers at the present time is the biggest bottleneck for their large scale use as energy source for pumping water for irrigation.

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