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ECONOMICS OF WOOD GASIFIER SYSTEMS FOR IRRIGATION PUMPING

INTRODUCTION

Small sized wood gasifiers coupled to diesel pumps (3-7 HP) for irrigation pumping are considered to be potential devices for diesel oil saving. Diesel replacements upto 88 per cent had been claimed in laboratory experiments (Damour, 1983). Diesel replacement value under field conditions was reported to be about 60 per cent (Durgaprasad *et al.*, 1985). Wood gasifier systems are commercially being manufactured in India by a few companies. The Department of Non-Conventional Energy Sources (DNES) had initiated a programme of setting up demonstration units of gasifier systems throughout the country with a view to establishing the viability of these systems under field conditions. The technical problems associated with the gasifier systems are reasonably well-known and are being researched further. However, the economic viability of the systems either at present or in the near future has not been studied in detail. Considering the facts that the gasifier systems are expensive and that wood is becoming a scarce fuel in many parts of the country, it might be desirable to carry out a detailed study of the economics of gasifier-based irrigation pumping systems. The present note uses the technique of Life Cycle Costing (LCC) to analyse the economic feasibility of wood gasifier systems for irrigation pumping in comparison with conventional diesel operated pumpsets.

METHOD OF ANALYSIS

There are several indices like cost-benefit ratio, internal rate of return (IRR), pay back period, etc., to compare between alternative means for the same end use. The Levelised Annual Cost (LAC) is one such index which provides a relatively simple means of estimating the impact of different techno-economic options on apparent relative costs. The LAC approach is equivalent to the Net Present Value (NPV) approach in which each of the cash flows is determined and discounted to a present value. The LAC is defined as

$$\text{LAC} = \frac{\text{Annual cost}}{\text{Annual energy output}} \quad \text{....(1)}$$

where

$$\text{Annualised cost} = \text{Capital investment} \times \text{CRF} + \text{annual operation, maintenance and repair costs} + \text{annual fuel costs}$$

The annual energy output for the pumping systems is proportional to the total amount of water pumped in m^3/year for a given system.

The capital recovery factor (CRF) converts the initial capital investment into a series of equal annual charges which have the same NPV. While dealing with economic (as distinct from financial) analysis, the CRF is a function of the economic discount rate (or the marginal return on capital) and the system life time, and can be obtained from the equation

$$CRF = r/1-(1+r)^{-OL} \quad ....(2)$$

where r is the annual discount rate and OL is the operating life of the system.

We take a 5 HP diesel pumpset as basis for calculations. A specific diesel consumption of 0.235 litres/(HP)(hr), which is typical for small systems is assumed. The annualised cost for this system is given by

$$AC_1 = I_1 \times CRF_1 + OMR_1 + 0.235 \times 5 \times N \times C_d \quad .... (3)$$

where AC is the annualised cost, I is the capital investment, OMR is the annual operation, maintenance and repair cost, N is the number of hours of operation in an year and C_d is the cost of diesel fuel in Rs./litre. Subscript 1 denotes the conventional system. The annual output, W_1 will depend, besides other parameters, on the capacity of the system and the operating hours, and can be written as

$$W_1 = k \times 5 \times N \quad .... (4)$$

where k is a proportionality constant depending on total head, friction losses, etc. The LAC is then given by

$$\begin{aligned} LAC_1 &= AC_1/W_1 \\ &= (I_1 \times CRF_1 + OMR_1 + 1.175 N C_d)/5kN \end{aligned} \quad .... (5)$$

A 5 HP gasifier coupled diesel pumpset would consume less diesel, and the reduced consumption is usually characterised by a 'diesel replacement value', expressed as a percentage or a fraction. The annual diesel consumption can then be expressed as 1.175 (1-DR)N, where DR is the diesel replacement in fractional terms. Thus for a 60 per cent diesel replacement, the value of DR would be 0.6. Besides diesel, wood is also consumed at a rate dependent on the efficiency of gasification. If we take the gasifier efficiency as 70 per cent, calorific value of wood as 4,000 kcal/kg., calorific value of producer gas as 1,100 kcal/Nm³ and a gas consumption figure of 10 Nm³/hr for a 5 HP system, the wood consumption figure can be calculated as 3.93 kg./hr. The annual wood consumption would then be equal to 3.93 N. The annualised cost for the gasifier system, denoted by subscript 2, can be written as

$$AC_2 = I_2 \times CRF_2 + OMR_2 + 1.175(1-DR)N\ C_d + 3.93 N C_w \quad .... (6)$$

where C_w is the cost of wood in Rs./kg.

There is a certain amount of derating of engine capacity while operating in a dual fuel mode. The derating is lower for CI (compression ignition) systems and higher for SI (spark ignition) systems. As a result, the water delivered by a gasifier coupled diesel pump would be lower, provided the total head, frictional losses in pipes, etc., are the same as for system 1. The annual discharge for system 2 can be written as

$$W_2 = k(1-x)\cdot 5\cdot N \qquad \text{.... (7)}$$

where x is the reduction (or derating) in the capacity expressed as a fraction. Typical derating figures of 10 to 20 per cent have been reported for gasifier coupled diesel engines. x would thus be typically 0.1 - 0.2. The LAC for system 2 can then be expressed as

$$LAC_2 = \frac{AC_2}{W_2}$$

$$= \frac{I_2 \times CRF_2 + OMR_2 + 1.175(1-DR)\,N\,C_d + 3.93\,N\,C_w}{k(1-x)\cdot 5\cdot N} \qquad \text{.... (8)}$$

The condition of economic viability can be expressed by the equation

$$LAC_2 \leq LAC_1 \qquad \text{.... (9)}$$

We define a factor f which is a ratio of LAC_2 to LAC_1. f is exactly equal to the ratio of net present value of costs of systems 2 and 1 for the same benefits and the condition of economic viability will then be expressed as

$$f \leq 1.0 \qquad \text{.... (10)}$$

The operating life of gasifiers is usually taken as ten years, whereas the diesel engine would have higher life time of about 15 years. We assume that the life of both systems 1 and 2 is the same at 15 years. As the discount rate will be the same for both systems, the CRF would thus be the same. The OMR costs for the gasifier system consist of three components, *viz.*, the OMR costs for diesel pump, OMR costs of gasifier and the cost of preparing wood chips from logs or bigger pieces. We assume that the OMR costs for diesel pump would be the same in both systems, although in many cases frequent breakdowns of engine have been reported for gasifier coupled engines. The costs of fuel preparation are directly proportional to the total amount of wood consumed. OMR_2 can thus be written as

$$OMR_2 = OMR_1 + OMR_g + y.\ 3.93\,N \qquad \text{.... (11)}$$

where y is the cost of cutting for 1 kg. of wood. If manual labour is used for cutting, then the local rate for labour should be taken for calculation and if an electric saw is used the cost of electricity should be taken.

With the above assumptions, an algebraic expression for f can be obtained as follows:

$$f = \frac{CRF \, . \, I_2 + OMR_1 + OMR_g + 1.175\,(1\text{-}DR)\,N\,C_d + 3.93\,N\,(C_w + y)}{(1\text{-}x)\,[CRF \, . \, I_1 + OMR_1 + 1.175\,N\,C_d]} \qquad \text{.... (12)}$$

It can be seen that f is a function of several parameters. In order to reduce the number of parameters, realistic values have been assigned for some of the parameters as follows: DR = 0.7; x = 0.1; I_1 = Rs.7,000; $OMR_1 = OMR_g$ = 500 Rs./year.
Equation (12) can now be expressed as

$$f = \frac{CRF. \, I_2 + 1{,}000 + 0.3525\,N\,C_d + 3.93\,N\,(C_w + y)}{(6300. \, CRF + 450 + 1.058\,N\,C_d)} \qquad \text{.... (13)}$$

RESULTS AND DISCUSSION

It can be seen from equation (13) that the main parameters affecting the economic viability function f are discount rate (r), capital cost of the gasifier pumping system (I_2), diesel price (C_d), number of hours of operation (N) and cost of wood chips (C_w + y). The discount rates considered in this paper are 0.12 and 0.09. The present cost of Rs.25,000 of the gasifier pump and a future possible cost of Rs.20,000 (for mass production) are taken for calculations. Three different diesel prices are considered: the present value of 3.5 Rs./litre, the value of 4.4 Rs./litre which includes a premium of 25 per cent accounting for scarcity of foreign exchange, and a value of 4.8 Rs./litre which represents a ten per cent increase in the diesel price. The cost of wood chips is varied from 0.2 - 1.0 Rs./litre and the number of hours of operation is varied from 500 - 3000 to account for regional variations. The variation of f with changes in the values of the parameters as above is shown in Tables I and II. Several conclusions are obvious from an examination of Tables I and II.

(1) For all the combinations of parameters considered, it is evident that gasifier based diesel pumps are economically not viable under the circumstances where $N \leq 2000$ hours *and* $(C_w + y) \geq 0.6$ Rs./kg.

(2) For $N \leq 1000$ hrs, the system is not viable at the present initial cost for *any* of the interest rates, diesel prices and wood chips prices considered in the study.

(3) For $(C_w + y) \geq 0.8$ Rs./kg., the system is not viable for *any* of the initial costs, discount rates, diesel prices and number of hours considered in the study.

For examining the viability of the gasifier system under real conditions, a detailed discussion on hours of operation and costs of wood chips is warranted.

For the particular end use of irrigation pumping, N depends on many factors like cropping pattern, cropping intensity, availability of alternate means of pumping, etc. The total number of hours of operation for electric pumpsets is available for various States of India (Government of India, 1983) and is shown in Table III. Similar data for diesel pumpsets are not available, but the data given in Table III can be taken as an upper limit for diesel pumps, because it is known that a significant number of diesel pumps are used as back-up devices due to non-availability of electricity (Ramesh and Thukral, 1988). The number of diesel pumps in each State has also been listed in Table III. To obtain an index of utilisation of diesel pumps, the total number of these pumps was divided by the total area irrigated by wells in a given State and tabulated. The hours of operation exceed 1000 only for the States of Haryana, Punjab, Rajasthan, Uttar Pradesh and Bihar and judging from conclusion (2) derived earlier, the feasibility of gasifier systems might be considered only for these States. It can be seen, however, from Tables I and II that for N ranging from 1000 to 2000 the system becomes viable for some combinations of discount rate, capital cost and diesel prices, *only* if the cost of wood chips is below 0.4 Re./kg.

TABLE I. SENSITIVITY OF f FOR $r = 0.12$

N (hours)	$C_w + y$	0.2	0.4	0.6	0.8	1.0
				$I_2 = 25,000$; $C_d = 3.5$		
500		1.76	1.88	2.00	2.13	2.25
1000		1.32	1.47	1.63	1.78	1.94
1500		1.11	1.28	1.45	1.62	1.79
2000		0.99	1.17	1.35	1.53	1.71
2500		0.91	1.10	1.28	1.47	1.65
3000		0.86	1.05	1.24	1.43	1.62
				$I_2 = 25,000$; $C_d = 4.4$		
500		1.58	1.68	1.79	1.90	2.00
1000		1.16	1.29	1.42	1.55	1.68
1500		0.98	1.12	1.26	1.40	1.54
2000		0.87	1.02	1.17	1.32	1.46
2500		0.81	0.96	1.11	1.26	1.41
3000		0.76	0.92	1.07	1.22	1.38
				$I_2 = 25,000$; $C_d = 4.8$		
500		1.51	1.61	1.71	1.81	1.91
1000		1.11	1.23	1.35	1.47	1.60
1500		0.93	1.06	1.20	1.33	1.46
2000		0.84	0.97	1.11	1.24	1.38
2500		0.77	0.91	1.05	1.19	1.33
3000		0.73	0.87	1.01	1.16	1.30
				$I_2 = 20,000$; $C_d = 3.5$		
500		1.53	1.66	1.78	1.90	2.02
1000		1.17	1.33	1.48	1.64	1.79
1500		1.01	1.18	1.35	1.52	1.69
2000		0.91	1.09	1.27	1.45	1.63
2500		0.85	1.03	1.22	1.40	1.59
3000		0.80	0.99	1.18	1.37	1.56
				$I_2 = 20,000$; $C_d = 4.4$		
500		1.38	1.49	1.59	1.70	1.80
1000		1.04	1.17	1.30	1.43	1.56
1500		0.89	1.03	1.17	1.31	1.46
2000		0.81	0.95	1.10	1.25	1.39
2500		0.75	0.90	1.05	1.20	1.36
3000		0.71	0.87	1.02	1.18	1.33
				$I_2 = 20,000$; Cd = 4.8		
500		1.32	1.42	1.52	1.62	1.72
1000		0.99	1.12	1.24	1.36	1.48
1500		0.85	0.98	1.11	1.24	1.38
2000		0.77	0.91	1.04	1.18	1.32
2500		0.72	0.86	1.00	1.14	1.28
3000		0.68	0.83	0.97	1.11	1.25

TABLE II. SENSITIVITY OF f FOR r = 0.09

N (hours)	$C_w + y$	0.2	0.4	0.6	0.8	1.0
			$I_2 = 25{,}000$; $C_d = 3.5$			
500		1.66	1.79	1.91	2.04	2.17
1000		1.24	1.40	1.56	1.72	1.88
1500		1.05	1.23	1.40	1.57	1.75
2000		0.94	1.12	1.31	1.49	1.67
2500		0.87	1.06	1.25	1.44	1.62
3000		0.82	1.01	1.21	1.40	1.59
			$I_2 = 25{,}000$; $C_d = 4.4$			
500		1.48	1.59	1.70	1.81	1.92
1000		1.09	1.23	1.36	1.49	1.63
1500		0.93	1.07	1.21	1.36	1.50
2000		0.83	0.98	1.13	1.28	1.43
2500		0.77	0.93	1.08	1.23	1.38
3000		0.73	0.89	1.04	1.20	1.35
			$I_2 = 25{,}000$; $C_d = 4.8$			
500		1.42	1.52	1.63	1.73	1.83
1000		1.04	1.17	1.29	1.42	1.54
1500		0.88	1.02	1.15	1.28	1.42
2000		0.80	0.93	1.07	1.21	1.35
2500		0.74	0.88	1.02	1.16	1.30
3000		0.70	0.84	0.99	1.13	1.27
			$I_2 = 20{,}000$; $C_d = 3.5$			
500		1.46	1.58	1.71	1.84	1.97
1000		1.12	1.27	1.43	1.59	1.75
1500		0.96	1.13	1.31	1.48	1.66
2000		0.87	1.05	1.24	1.42	1.60
2500		0.81	1.00	1.19	1.38	1.56
3000		0.77	0.96	1.16	1.35	1.54
			$I_2 = 20{,}000$; $C_d = 4.4$			
500		1.31	1.42	1.53	1.64	1.75
1000		0.99	1.12	1.26	1.39	1.52
1500		0.85	0.99	1.14	1.28	1.43
2000		0.77	0.92	1.07	1.22	1.37
2500		0.72	0.88	1.03	1.18	1.34
3000		0.69	0.85	1.00	1.16	1.31
			$I_2 = 20{,}000$; Cd = 4.8			
500		1.25	1.36	1.46	1.56	1.67
1000		0.94	1.07	1.19	1.32	1.44
1500		0.81	0.95	1.08	1.21	1.35
2000		0.74	0.88	1.02	1.16	1.29
2500		0.70	0.84	0.98	1.12	1.26
3000		0.66	0.81	0.95	1.09	1.24

TABLE III. INDICES SHOWING UTILISATION OF DIESEL PUMPSETS IN VARIOUS STATES

State	N (hours/year)	No. of diesel pumpsets* 1978-79	Net area irrigated by wells† ('000 ha.) (1982-83)	No. of diesel pumps per 1,000 ha.
Haryana	1086	70,000	1,090	64.2
Punjab	1636	2,68,000	2,080	128.8
Rajasthan	1081	58,000	1,997	29.0
Uttar Pradesh	1625	8,51,000	6,071	140.2
Gujarat	722	5,67,500	-	-
Madhya Pradesh	465	98,170	1,123	87.4
Maharashtra	888	2,14,470	-	-
Bihar	1298	1,33,000	855	155.6
Orissa	542	9,100	-	-
West Bengal	674	86,500	618	140.0
Andhra Pradesh	758	1,45,331	839	173.2
Karnataka	397	43,945	418	105.1
Kerala	277	26,649	-	-
Tamil Nadu	677	1,17,124	959	122.1

* *Source:* Indian Institute of Petroleum(1978).
† *Source:* Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

TABLE IV. RETAIL PRICES OF FIREWOOOD IN SELECTED CENTRES

(*Rs. per kg.*)

Month/Year	Calcutta	Delhi	Madras	Bangalore	Hyderabad
April 1978	0.35	0.35	0.32	0.23	0.25
April 1979	0.43	0.47	0.41	0.24	0.30
April 1980	0.48	0.48	0.48	0.34	0.31
April 1981	0.57	0.61	0.52	0.38	0.40
April 1982	0.66	0.71	0.55	0.45	0.49
April 1983	0.66	0.80	0.57	0.58	0.58
April 1984	0.68	0.96	0.66	0.59	0.65
April 1985	0.79	1.04	0.71	0.63	0.66
April 1986	0.98	1.20	0.72	0.70	0.70
April 1987	1.04	1.23	0.72	0.66	0.64

TABLE V. INDICES SHOWING THE AVAILABILITY/SCARCITY OF WOOD FOR GASIFICATION PURPOSES

State	Annual production of fuelwood* (million M³)	Annual requirement of fuelwood* (millioon M³)	Deficit* (million M³)	Average per capita consumption of firewood† (kg./yr)	Average per capita consumption of crop waste† (kg./yr)	Average per capita consumption of dung cake† (kg./yr)
Haryana	0.11	3.4	3.29	10.5	78.3	255.7
Punjab	0.04	4.4	4.36	23.2	115.1	210.7
Rajasthan	0.23	1.0	0.77	49.2	15.0	140.8
Uttar Pradesh	2.09	28.9	26.81	20.8	62.7	211.0
Gujarat	0.18	8.0	7.82	32.4	8.5	91.6
Madhya Pradesh	1.41	14.1	12.69	61.8	45.6	189.5
Maharashtra	1.40	16.6	15.20	71.2	14.5	89.5
Bihar	0.36	18.7	18.34	11.5	79.8	265.4
Orissa	0.61	7.4	6.79	25.2	28.0	122.0
West Bengal	0.53	15.3	14.77	18.3	156.8	98.3
Andhra Pradesh	0.97	14.1	13.13	48.7	36.1	46.6
Karnataka	1.71	9.8	8.09	46.8	52.2	8.7
Kerala	0.55	7.1	6.55	31.4	83.2	0.2
Tamil Nadu	0.29	13.0	12.71	51.9	40.7	40.8

* *Source: Urja* (Energy) *Update*, May 1987 (New Delhi).
† *Source:* NCAER (1981).

It is a widely recognised fact that wood has become a scarce commodity in the last few years due to a variety of reasons like large scale deforestation and increased demand for cooking energy. As a result, the retail prices of wood have increased steeply in the last few years (CMIE, 1988). The tendency of retail prices at a few centres is shown in Table IV. Judging from the present retail prices of firewood and from conclusion (3) above, it is apparent that operating the gasifier system with *purchased* wood is clearly not a viable proposition. It might be argued that these prices do not reflect the actual cost of wood and include other costs like those for transport, etc. The cost of firewood (*Prosopis*) grown on wastelands has been estimated to be Re. 0.40 per kg. (Chaturvedi, 1985). The cost of cutting wood into small pieces is about 0.05 Re./kg. by electric saw and 0.5 Re./kg. if manual labour is employed, assuming that 20 kg. wood can be processed per man-day and that the labour rates are 10 Rs./man-day. The lowest cost of wood chips would thus be about 0.45 Re./kg. At this cost of wood chips, as can be seen from Tables I and II, the gasifier system is not viable economically for most of the combinations and would at best be marginally viable under the best circumstances of low capital cost, low discount rate and high diesel price.

There is some debate among biomass specialists regarding the yield and hence the cost of production of firewood from social and agro-forestry. Under favourable conditions, it is perhaps possible to obtain wood chips at a price less than 0.45 Re./kg. But in view of the scarcity of fuelwood, it is doubtful whether wood would be made available for gasification purposes rather than for selling in the market at higher returns. Several indices which show the scarcity/availability of firewood are listed in Table V for each State. The States of Haryana, Punjab, Rajasthan, Uttar Pradesh and Bihar, which were considered earlier from the point of view of operating hours, are marked by low per capita consumption of firewood, and (logically as a result) high per capita consumption of crop residues and dung cakes. Hence, it might be expected that large scale programmes of plantation on wasteland would not necessarily pave the way for large scale promotion of wood gasifier units for irrigation pumping.

CONCLUSIONS

Small scale gasifier systems coupled to diesel pumps for irrigation do not seem to be economically viable, compared to diesel-alone systems. The main parameters affecting economic viability are (*i*) capital cost of gasifier equipment, (*ii*) discount rate, (*iii*) cost of diesel, (*iv*) number of hours of operation and (*v*) cost of wood, including cutting costs. Even under favourable conditions of lower capital cost, lower discount rate and higher diesel prices, the cost of wood and the number of operating hours obtaining in various States do not permit viability in the near future. Hence, it might be desirable to concentrate R & D efforts in gasification on utilising essentially waste material. Also, as the operating hours per year are generally low for irrigation pumping, it seems desirable to limit the use of gasifier systems for other applications like power generation, process heat, etc.

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