PRODUCER GAS FROM TRASH AND BAGASSE AS A VIABLE SUPPLEMENTARY FUEL FOR DIESEL ENGINES

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Abstract

The gasification of trash and bagasse pellets to provide supplementary fuel for a diesel engine is discussed. The problems involved in, and the equipment and modifications necessary for such a project are presented and the results suggest that producer gas is a viable and economic alternative fuel for stationary engines.

Introduction

Producer gas has been used as fuel since the 1920's and during World War II interest in this gas increased in proportion to the decline in supply of fossil fuels. Small producer gas units were used successfully on trucks and tractors in Europe, particularly in Sweden, and also in Japan (Goss *et al*[1]). Interest in producer gas waned when fossil fuel again became readily available, but has been re-awakened since the large increases in the price of crude oil during the past few years.

Considerable progress has been made in the design of generators, filtration methods and types of fuels used. Since no data were available, workers at the Experiment Station began to investigate the feasibility of using bagasse and trash pellets to produce gas and to study the necessary adaptations to machinery so that supplementary fuel can be used in a stationary diesel engine.

Producer gas

Producer gas is a combination of gases formed by the passage of air across a bed of hot coals, then into anaerobic conditions where reduction and cooling take place. The combustible components are formed during the following reactions:

- carbon monoxide is produced by the partial combustion of carbon

$$2C + O_2 \rightarrow 2CO$$

- hydrogen and more carbon monoxide is formed by the reaction of steam on glowing hot carbon

$$C + H_2O \rightarrow CO + H_2$$

- methane is produced by the action of some of the above hydrogen on glowing hot carbon

$$C + 2H_2 \rightarrow CH_4$$

The constituents of producer gas are listed in Table 1 (Anon[2]).

TABLE 1

Constituents of producer gas

Gas		% by volume
Carbon monoxide	CO	21,4
Hydrogen	H_2	13,6
Methane	CH_4	2,9
Carbon dioxide	CO_2	9,6
Oxygen	O_2	1,2
Nitrogen and Argon	N_2 and Ar_2	51,5

Producer gas generators

There are three basic types of producer gas generators; cross-, down- and up-draught. They are generally used for small spark ignition engines, spark ignition and compression ignition engines and for large scale heating respectively.

The down-draught gasifier is the most commonly used generator because it is particularly suited to most internal combustion engines. An advantage over the up-draught type is that any tars and volatile pyrolysis products must pass the combustion and reduction zones and are cracked into fuel gases before leaving the gasifier (Anon[2]).

Producer gas generation at La Mercy

In 1981 a cross-draught producer gas generator was built from plans obtained from the Council for Scientific and Industrial Research (CSIR) and the National Timber Research Institute (NTRI). Its limitations, particularly with respect to burning the large quantity of tar which results from using bagasse pellets, soon became obvious. Attempts were made to convert it to a down-draught type but it failed to produce sufficient gas. The project was therefore shelved until 1982 when a gas generator, together with its filtration system, was borrowed from the Department of Agriculture and Fisheries (DAF) (Figure 1).

Two water scrubbers which were used in series after the main filter bank were built to work in conjunction with the borrowed gasifier (Figure 2).

By using water scrubbers, much of the main filter bank can be eliminated. This system is shown in Figure 3.

System specifications

Gasifier

The gasifier is an Imbert type down-draught producer gas generator with a stainless steel hopper with a capacity of 275ℓ. The conical hearth is made of cast iron, the angle of the wall is 53° to the vertical and the choke orifice has a 130 mm diameter. Five nozzles are arranged in a ring, 260 mm in diameter 104 mm above the orifice. An additional choke plate, 80 mm in diameter was added to meet the requirements set out by Horvath[3] (Table 2).

TABLE 2

Hearth orifice and corresponding engine sizes

Hearth orifice size diameter (mm)	Engine size cc
60	1 500
80	2 000
100	3 600
120	5 000
120 - 150	6 000

Nozzle dimensions were, for practical reasons, left unchanged (Table 3).

TABLE 3

Hearth orifice sizes and corresponding nozzle diameters

Hearth orifice size diameter (mm)	Nozzle ID diameter (mm)	Nozzle number
60	10	5
100	10	5
130	13	5
150	13	5

The reduction zone consists of a gap between the bottom of the hearth skirt and the grid which is situated 120 mm above the ash-pit floor.

Details of the gasifier components are given in Figure 4.

Filtration

Filtration consists of a primary cooling zone between the hopper and outer wall of the gasifier; total depth is approximately 400 mm. Gas is extracted beneath the condensation gutter after which it passes through a heavy particle trap. It is then piped to the cyclone which extracts most of the remaining heavy particles. The gas then enters the water scrubbers via two filters and a radiator which cools it to between 40 and 45°C. At this temperature, dew point causes precipitation of any remaining moisture and the gas condenses to an acceptable level to avoid fuel starvation. The water scrubbers are made from rolled sheets of galvanised iron (16 ga), 1 m in circumference and 1,5 m in length. They are seam welded and conical caps are fitted to the top and bottom. Gas enters 600 mm from the top and the exit point is at the top of the cone. The gas enters the bottom chamber and then passes through a bed of charcoal resting on a mesh screen (Figure 5). Water is sprayed onto the charcoal in a cone formation by sprayers fitted through the walls of the scrubber. The water may be recirculated or, as with the La Mercy rig, allowed to run to waste. The sprayers were fed from a conventional household water supply.

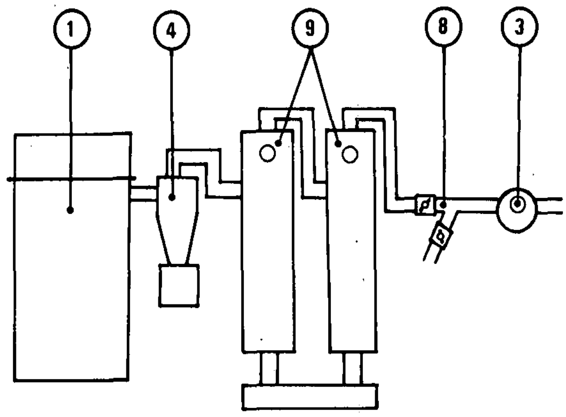


FIGURE 3 Proposed layout of filtration system.

After final cleaning by the water scrubbers, the gas is mixed with air in a venturi controlled by a butterfly valve. Final mixing and cleaning of the air and the gas takes place in a truck

LEGEND (applicable to diagrams 1, 2 and 3)

1 producer gas generator
2 heavy particle separator
3 blower
4 cyclone
5 1st filter
6 radiator-coder
7 2nd filter
8 butterfly valves and venturi
9 water scrubbers in series

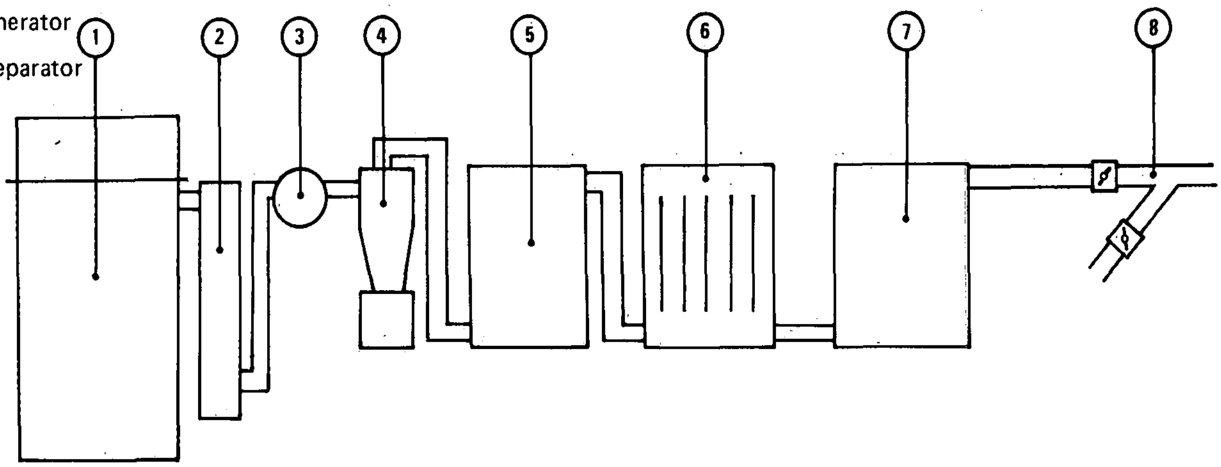


FIGURE 1 Schematic layout of gas generator and filters.

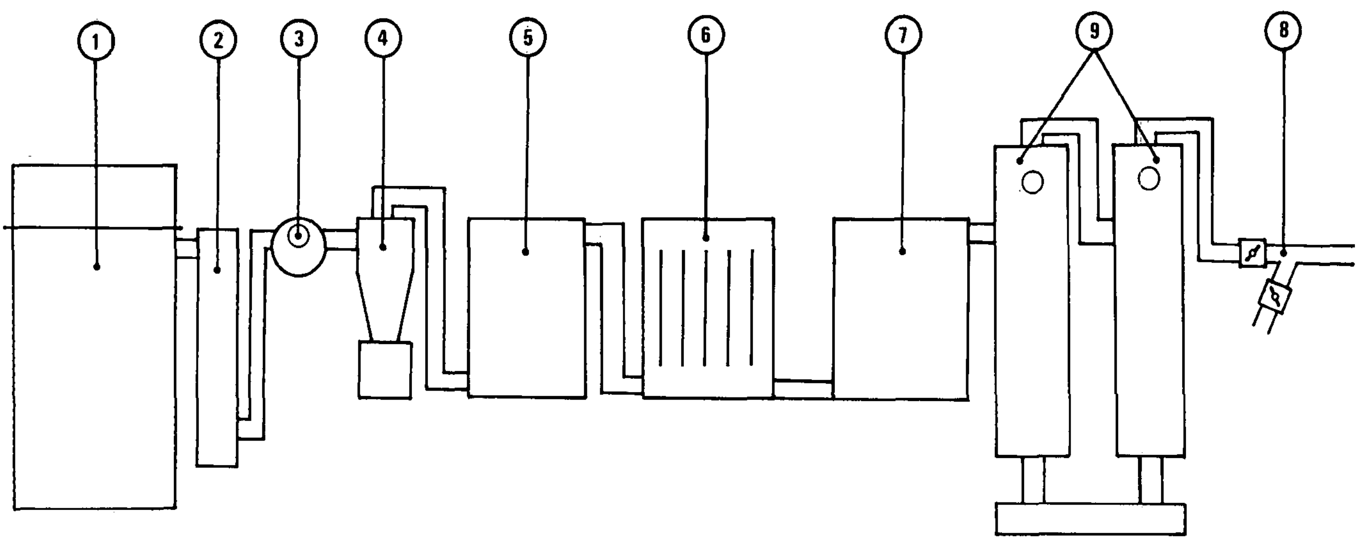


FIGURE 2 Schematic layout of gas generator at La Mercy.

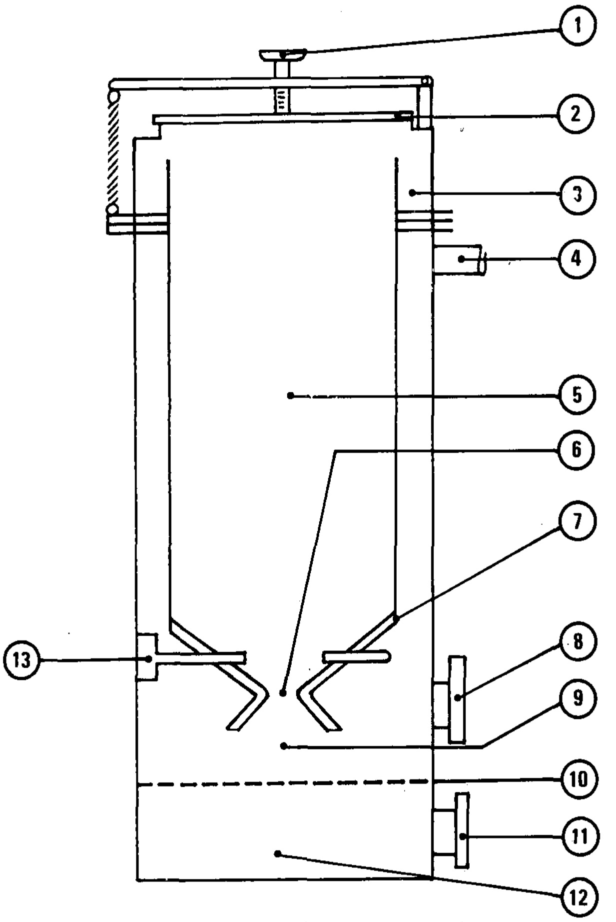


FIGURE 4 Cross section of an Imbert type producer gas generator.

type airfilter fitted to the air inlet manifold of the engine (Figure 6).

Starting fan

An electrically powered blower is used during the start up stage and draws air across the hearth zone while ignition is in progress. It continues to draw air until gas appears at the blower outlet. It would be more practical to place the blower as close to the engine as possible so that the filtration system becomes charged with gas before the engine is started.

Power source

A 1948 cc Peugeot 404D naturally aspirated engine was used. It had a power output of 41,2 kW (DIN) at 4 500 rpm and 107,9 Nm torque (DIN) at 2 000 rpm. Compression ratio was 21,8:1. The fuel pump was a Rotodiesel rated at 2,7 cc per 100 shots at 1 500 rpm. The engine was bought in running order but the power output was 50% lower than that specified. It was not considered to be worthwhile to overhaul the engine but the injector metering pressure was readjusted. Derating the diesel injector pump was done by a specialist firm because the Rotodiesel pump employs a cam system of metering which requires adjustment with specialised equipment.

Power sink and dynamometer

An M & W P2000 pto dynamometer was initially planned as the power sink but it was too insensitive to small changes in torque. An hydraulic unit was then built from available parts. This consisted of two 300ℓ oil tanks mounted on a disused disc-harrow frame and a double Ushida pump was mounted between them. Pump capacities were 80 and 50 ℓ/min at 1 000 rpm feeding a 25,4 mm pipe with a manually operated restrictor valve. A pressure relief valve circumvented the restrictor valve at pressures greater than 20 MPa. Oil was returned to the tanks via three filters which were mounted in a parallel circuit (Figure 6).

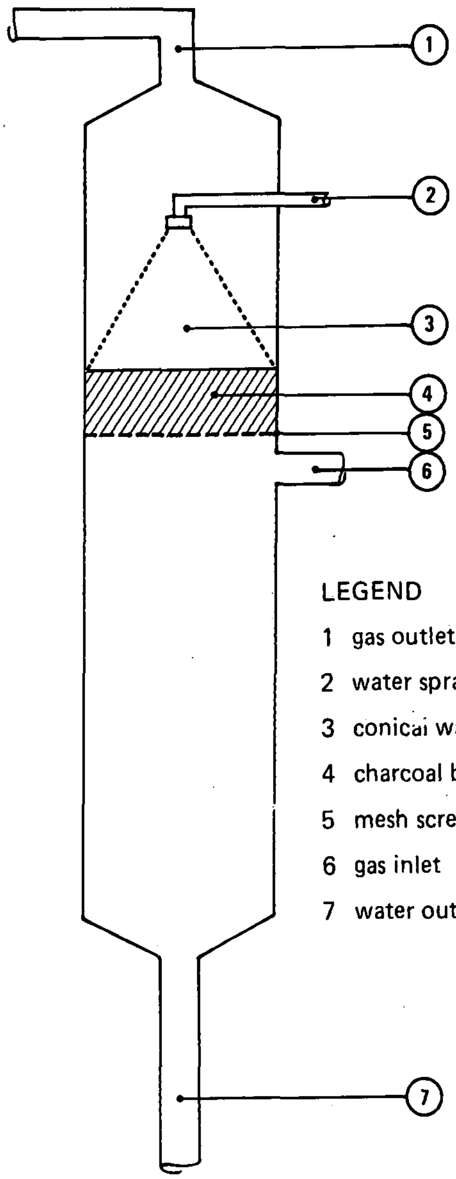


FIGURE 5 Diagram showing section of water scrubbers.

Because the engine and pump speeds were different, a McConnel 3,14:1 reduction gearbox was mounted between the drive shaft and the pump carriage. The pump mounting bracket was suspended between bearings and attached to this was a torque arm 1 020 mm long.

Instrumentation

Measurements were made as follows:

- Torque was obtained by measuring the force exerted by the torque arm on a strain-gauge type load-cell. The reading was given in kg (correct to two decimal places), by a Newport amplifier with LED display. It was then converted to read torque in Nm by multiplying the reading by 10.
- Speed was measured with a Compact 6000 digital tachometer mounted on a stand and positioned to face a target tape attached to the drive shaft.
- Power was calculated from the equation

$$\frac{\text{Speed (rpm)} \times \text{torque (Nm)}}{9\,550} = \text{power in kW}$$

- Fuel consumption was measured in ml, by a Micro Oval II fuel flow meter on an electro-mechanical counter. By using a stopwatch or timer relay, set for periods of 15 seconds, the flow rate in ℓ/h was determined by multiplying the counter reading by 0,24.

LEGEND

1 gas/air inlet
2 truck type air filter
3 air inlet manifold
4 exhaust manifold
5 drive shaft
6 filter bank
7 hydraulic oil tanks
8 hydraulic pumps and frame
9 pressure relief valve
10 restriction valve
11 load cell
12 torque arm
13 instrument panel
14 radiator

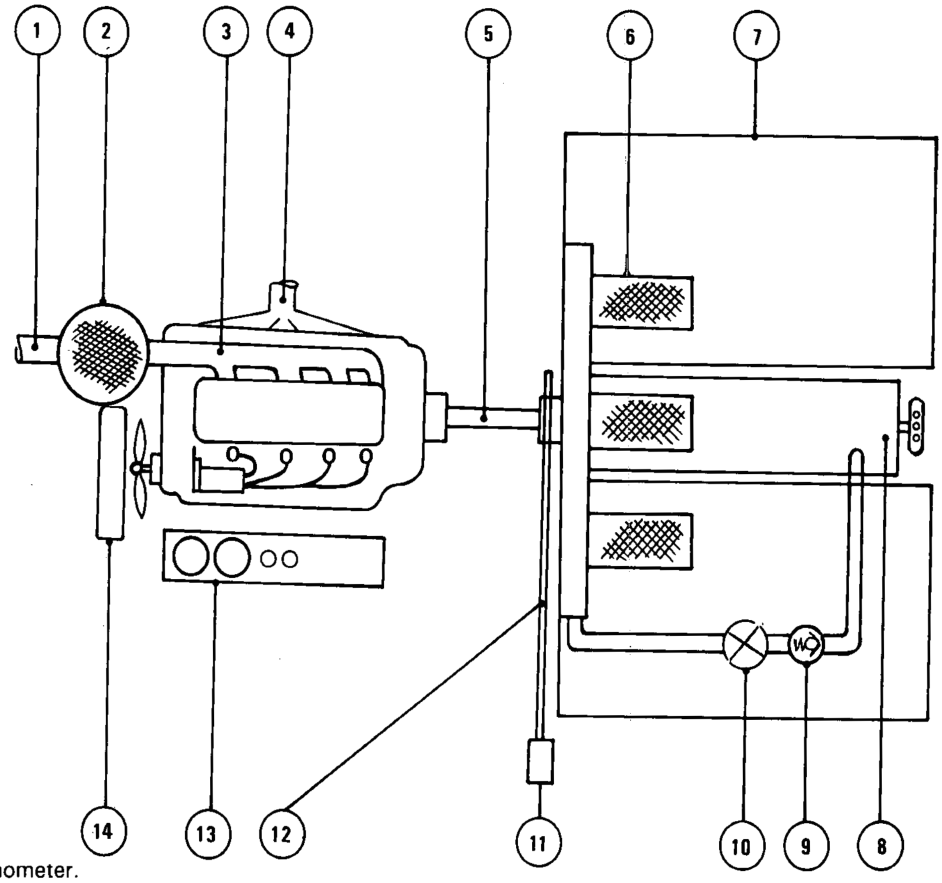
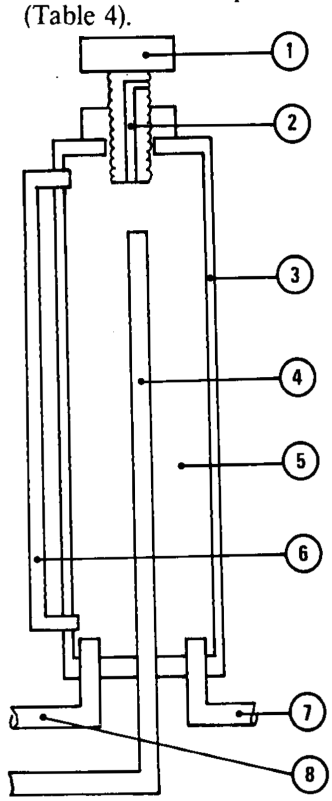


FIGURE 6 Schematic plan view of engine and dynamometer.

- Specific fuel consumption (SFC) was calculated from the power and fuel consumption:

$$\frac{kW}{\ell/h} = kW\ h/\ell$$

- Additional instruments used to monitor performance and engine conditions included an M & W exhaust temperature pyrometer, a Brookes tube rotameter and manometer tubes placed across the gas and air butterfly valves. A conventional office fan was adequate for additional cooling in most cases (Table 4).



LEGEND

1 air-bleed screw
2 air-bleed duct
3 body of trap
4 bypass fuel return line
5 fuel chamber
6 sight glass
7 fuel line from tank
8 fuel line to injector pump.

FIGURE 7 Schematic section of diesel fuel air trap.

TABLE 4
Coolant temperature of engine, using diesel only, at maximum power

	°C
Standard	100 (shutdown)
30 % derated	90
50% derated	70

To eliminate air from the diesel fuel system when bypass fuel was returned to the fuel line on the engine side of the fuel flow meter, an air trap was constructed so that only the fuel that was used was measured (Figure 7).

Pelletized bagasse

Although gas was produced from charcoal and wood chips during the setting up stages, the primary objective was to test the potential of sugarcane waste products as a fuel source. Bagasse pellets, which are manufactured as a high roughage cattle feed, were used (Table 5).

TABLE 5
Constituents of bagasse pellets

Constituents		Mass g/kg
Protein	(min)	25
Fat	(min)	8
Fibre	(max)	350
Moisture	(max)	100
Calcium	(max)	2,5
Phosphorus	(min)	0,2

Bagasse pellets are manufactured as follows: bagasse from the millyard dump contains about 49% moisture so it is first dried in a rotating drier which is fed with hot air from a coal-fired furnace. About 150 kg crushed coal is used per ton of bagasse and the moisture level is reduced to between 6 and 8%. The bagasse is then fed into a disintegrator with a 9,5 mm screen before it is transferred to the pelletizing machine where it is combined with steam and 10% molasses, which assists in binding the pellet (Tongaat Milling[7]). The die used in the pelletizer produced pellets 11 mm in diameter but it was felt that the pellets were too small for the existing gasifier, and that a larger diameter would have been preferable (van der Merwe[9]). Bagasse pellets cost R65,00 per ton f.o.r. Maidstone Mill and the cost of burning pellets at various speeds is presented in Table 6.

TABLE 6

Mass of pellets burned at various speeds

Speed rpm	Mass kg	Cost @ 6,5c/kg	Speed rpm	Mass kg	Cost @ 6,5c/kg
30% derate			50% derate		
2 000	2,7	17,5	2 000	1,4	9,0
2 500	3,0	19,5	2 250	1,5	9,8
3 000	3,3	21,5	2 500	1,7	11,0
3 500	3,6	23,4	2 750	1,8	11,4
4 000	3,9	25,4	3 000	2,0	13,0
4 500	4,2	27,2	3 250	2,1	13,8
5 000	4,5	29,0			

Pelletized trash

Trash was collected from a field yielding 80 t cane/ha which had been harvested by the Sasaby green cane harvester. The trash blanket was estimated to be 20 t/ha since 1,86 tons was removed from approximately 0,1 ha after a drying time of three weeks. The trash was then cut with an LM Junior chaff cutter and packed by a Bell loader into a portable bin and taken to the Maidstone mill for further processing. The trash was not fine enough for the drying process so it was milled in a hammermill through a 25 mm screen. The milling took four and a half hours to complete. The procedure for making pellets was the same as that for bagasse except that the steam and molasses components had to be varied slightly to achieve adequate compaction. A total of 980 kg of pellets was recovered from the plant.

Unfortunately the trash pellets were unsuitable for gasification because they easily broke into fine particles. Even after sieving to retain pellets which were 400 mm^3 and larger, they disintegrated during transport and when the hopper was being filled. This resulted in a compact mass of fines which inhibited air flow in the gasifier, and temperatures were therefore too low to sustain carbonising and gas formation.

Subsequent attempts at pelletizing trash have resulted in better quality pellets. Previously pelletized trash was remilled in a hammermill with a 6 mm diameter screen and then fed into a pelletizer at a very slow rate. It soon became obvious that the high fibre content (90%) required very high compaction rates. Although water was added the heat build-up and compaction forces soon blocked the die. Further pelleting was abandoned because the risk of permanent damage to the die was high. The quality of the few pellets that were extruded was exceptionally good and compares with bagasse in their suitability for gasification.

It was suggested that future processing would be facilitated by the inclusion of buffer material such as Bentonite and the addition of between 2,5% and 5% more molasses. The disuse of steam appeared to have been important in the higher density of the remilled pellets (Jacobs[4]).

When pelletizing trash, some of the costs that should be borne in mind are the:

- cost of extracting trash from the field
- loss of the equivalent nutritional value of trash in terms of cost of nutrient replacement (Thompson[6])(Table 7).
- cost of hammermilling, drying, pelletizing, handling and transport
- net potential energy of the pellets which should be greater than the total energy required to make them
- net saving in fuel cost should exceed the cost of pelletizing
- effect of a trash blanket on the conservation of soil and moisture compared with its removal.

TABLE 7

Available trash and nutrient removal rates from two varieties of cane

Variety (trash oven-dried)	100 t cane/ha t trash/ha	Nutrient value (kg)					Value R
		N	P	K	Mg	Ca	
NCo 310	21,87	187	8,8	183	81	99	299
NCo 376 dryland	15,84	152	17,6	167	59	84	261
NCo 376 irrigated	17,86	178	19,8	328	75	90	359

Note: Prices are based on current prices and do not include transport and handling costs

Examples of the power requirements, output and cost of some of the available range of pelletizers are shown in Table 8. In most cases, the lower output figure should be used when estimating cost. (Note: costs are based on those of November 1978) (Horvath *et al*[5]).

TABLE 8

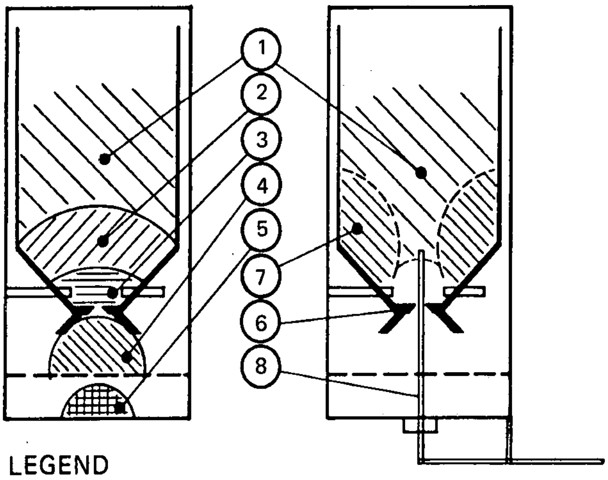
Selected types of cubing and pelleting machines

Type	Capital cost R	Output kg/h	Power requirements kW
Cubing	5 000	650 - 1 700	30
	8 500	1 000 - 4 000	35
	9 500	1 000 - 4 000	40
Pelleting	3 500	650 - 1 700	18
	16 000	1 250 - 5 000	55
	47 000	3 500 - 15 000	160 - 200

Factors to be considered when producing gas

- Particle size: the relationship between the size of the particle and hearth orifice is critical in that undersized particles will block the air flow towards the hearth and inhibit excess steam from rising towards the condensate gutter (Horvath[3]). Unless steam has a free upward passage, it will react with the pellets causing them to swell and lodge firmly above the hearth, which is the prime cause of bridging.
- Tar formation: temperatures above 700°C reduce the formation of tar since the distillation components appear as combustible gas (Horvath[3]). The correct size of hearth and draught to maintain sufficient throughput of air to keep hearth temperatures between 700°C and 900°C are essential.
- Steam: the moisture content in bagasse pellets was sufficiently high to cause breakdown in pellet density. Excess steam therefore condensed in the gas line instead of permeating upward to the condensation gutter.
- Bridging: problems with bridging occurred around the nozzles and extended upwards and towards the centre. As a result, a steel probe which could be levered in a reciprocating motion to dislodge bridged material was fitted to the underside of the gas generator. This was only partially successful (Figure 8).

- Clinker: the formation of clinker from soil particles contained in the bagasse and trash pellets could be a problem if the hearth orifice were too small to allow free passage of clinker through the reduction zone.



LEGEND

(1) Fuel
(2) Caramelising zone
(3) Carbonising zone
(4) Reduction zone
(5) Ash
(6) Modified hearth orifice restrictor in place
(7) Bridged material
(8) Prod

FIGURE 8 Cross section of components and fuel conditions.

Performance

The performance of the engine when running on gas and diesel is compared with the performance when operating on diesel only. Wide variations in observations for each particular test run while using gas were due mainly to the occasional stochiometric imbalance. Smooth curves were fitted to the data using polynomial regression equations.

Inter-related factors influencing the curves are bridging of the fuel in the gasifier, engine rpm and the type of filtration. These factors affect the quantity and quality of the gas and indicate the need for an auxiliary governor to control the air:gas ratio, a principle expounded by Ongunlowo, Chancellor & Goss[8].

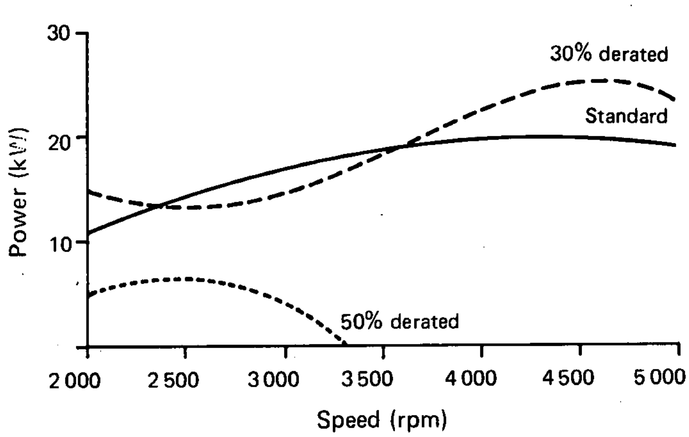


FIGURE 9 Power versus speed for 2 levels of derating: 50%, 30% – gas and diesel (and standard)

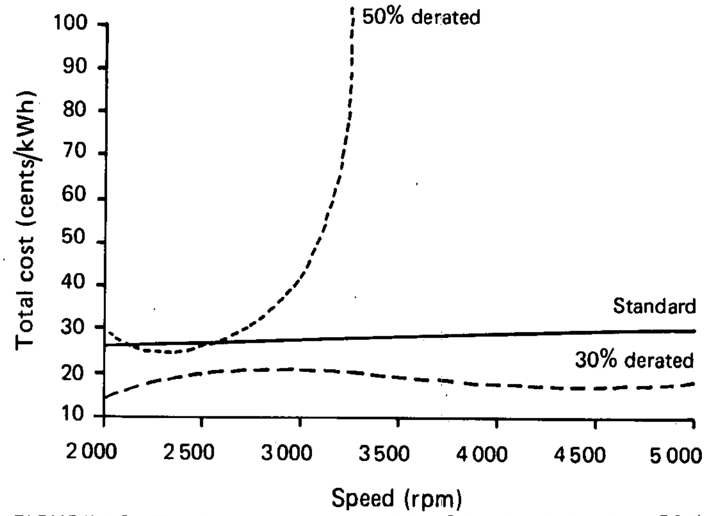


FIGURE 10 Total cost versus speed for 3 levels of derating: 50%, 30% and standard – gas and diesel.

The costings given in Table 9 are approximations only, because some difficulty was experienced when measuring the quantity of pellets used during a one hour test run. The mass and cost were calculated from measurements (to the nearest 5 mm) of the hopper depth. Costs are based on fuel costs only so they do not include capital, handling, operator or transport costs. Diesel costs are based on the current farm price of 44,8 cents per litre.

TABLE 9

Results from Figures 9 and 10

Reference	Speed rpm	Fuel ℓ/h	SFC kWh/ℓ	Power kW	Diesel cents /kWh	Gas cents /kWh	Total cents /kWh	Cost saving %
4.1.1-3 Diesel only	2 000	6,91	1,59	11,37	27,23		27,37	
	2 500	8,91	1,59	14,53	27,47		27,47	
	3 000	10,57	1,57	16,98	27,89		27,89	
	3 500	11,88	1,54	18,71	28,45		28,45	
	4 000	12,84	1,51	19,73	29,16		29,16	
	4 500	13,45	1,46	20,04	30,07		30,07	
	5 000	13,72	1,39	19,63	31,31		31,31	
4.2.1-3 30% derate diesel only	2 000	4,97	1,76	8,72	25,53		25,53	
	2 500	5,69	1,79	10,19	25,02		25,02	
	3 000	6,43	1,78	11,45	25,16		25,16	
	3 500	7,22	1,71	12,35	26,19		26,19	
	4 000	8,04	1,59	12,78	28,18		28,18	
	4 500	8,89	1,41	12,54	31,76		31,76	
	5 000	9,78	1,18	11,54	37,97		37,97	
4.3.1-3 30 % derate bagasse	2 000	4,56	3,32	15,14	13,49	1,16	14,65	46
	2 500	5,49	2,39	13,12	18,75	1,49	20,24	26
	3 000	6,19	2,30	14,24	19,47	1,51	20,98	25
	3 500	6,72	2,68	18,01	16,77	1,30	18,07	36
	4 000	7,14	3,17	22,63	14,14	1,12	15,26	48
	4 500	7,49	3,40	25,47	14,04	1,07	15,11	50
	5 000	7,84	3,01	23,60	14,88	1,23	16,11	49
4.4.1-3 50% derate diesel only	2 000	3,45	1,37	5,21	29,67		29,67	
	2 250	3,71	1,13	4,81	34,56		34,56	
	2 500	3,99	1,14	5,50	32,50		32,50	
	2 750	4,27	1,18	6,31	30,32		30,32	
	3 000	4,57	1,04	6,31	32,45		32,45	
	3 250	4,87	0,51	4,55	47,97		47,97	
4.5.1-3 50% derate bagasse	2 000	3,38	1,68	5,37	28,20	1,68	29,88	– 9
	2 250	3,73	1,81	6,61	25,28	1,48	26,76	
	2 500	4,01	1,75	6,89	26,07	1,60	27,67	– 1
	2 750	4,23	1,51	6,21	30,52	1,84	32,36	
	3 000	4,38	1,08	4,57	42,94	2,85	45,33	– 38
	3 250	4,46	0,47	1,98	100,91	6,97	107,88	

It is evident that the supply of gas from the generator and the requirement of gas by the engine should be matched for maximum saving of costs. If these quantities are not matched, such as at La Mercy, the 50% derate level causes a drop in the engine speed below the swept volume per minute level required to maintain hearth temperatures between 700°C and 900°C which are the temperatures between which optimum gasification occurs (Table 9). It can then become more expensive to use producer gas than diesel.

For example, at the 30% derate level there is a 50% saving in fuel at maximum power, and an additional 5,4 kW is obtained at comparable engine speeds. However, the standard power levels and torque outputs indicated by the manufacturer are initially 50% lower, so one could expect a drop of about 20% in indicated thermal efficiency when using producer gas because of the difference in the energy content of the gas and diesel (Ongunlowo *et al*[8]) (Table 10).

TABLE 10

Comparison of energy of some fuels

Fuel	MJ
Petroleum	23,19/ℓ
Diesel	27,05/ℓ
Producer gas (dry cotton stalks)	11,86/kg

Conclusion

When a stationary engine is fuelled with producer gas, savings greater than those shown in this paper could be expected provided that the production of clean gas matches the requirements of the engine. A cost-related investigation into the proposed use of fuels that require conversion into a form acceptable for use in a producer gas generator should be considered.

Acknowledgements

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