Experience with Gasifiers for 3.7-kw Engines

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Experience With Gasifiers for 3.7-kW Engines

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Energy technologies must of course vary from society to society. On the other hand, lessons learned from previous attempts, successful or otherwise, can be extremely helpful to a would-be innovator. The following article describes, in detail, how a new type of gasifier was developed in India. The discussion includes information on all stages, including various prototypes.

The renewal of interest in the development of biomass gasifiers and their use has been due to the sharp global reminders concerning the non-renewable nature of petroleum-based energy resources. Most of the important developments in the long history of gasifiers occurred before or during the second world war and these have been well documented (1). Gasifier designs for more than 15 kW (greater than 20 horsepower) have been presented in the Solar Energy Research Institute (SERI) translation of *Generator Gas—The Swedish Experience* (1). There are, however, no guidelines for designing for lower ratings, although a few hints about the problems of gasifier operation can be found (1, 2).

India has about six million pump sets using diesel engines of 3.7 kW capacity. It was recognized that running these pump sets with producer gas from a wood gasifier (in a dual fuel mode) could constitute a significant conservation measure for oil resources, and also make the user somewhat less dependent on a centralized supply of diesel. It is in this context that a project was undertaken in 1981 to develop a gasifier for the 3.7-kW diesel engine pump set.

In about a year a design using extrapolated values of parameters given in the SERI report was developed, and tests showed an average replacement of diesel of about 80 percent at full power (3). The gas produced by the gasifier and the cooler scrubber system was occasionally characterized by excessive levels of tar. The system required frequent operator attention and often had to be dismantled for maintenance. For ease of dismantling, some of the major junctions on the reactor shell were not welded, but were made leakproof using fire clay and plaster of Paris, which led to the development of cracks, eventually lowering performance. The operation became reliable only when this practice was abandoned completely and fully welded joints and water seals were used.

In the second phase of the project, initiated in 1983, the objective was to develop a prototype that would run reliably and yield good-quality gas while demanding very little attention. The literature (1, 3) continued to provide help in either confirming or discarding our suspicions and hopes of how each new concept would alter the performance of the reactor. As an illustration of this, we considered several earlier designs that have various provisions for proper drying and charring of wood chips inside the reactor. This concept has been adapted in the present design as a combination of a unique water seal and high-point gas offtake to obtain reliable operation.

During several runs when the gas quality was bad it was necessary to dismantle the system and examine various parts. This required almost half a day in the early prototypes, but the time was reduced to thirty minutes in the final version. In a field environment it would be a great help if the system could be dismantled and reassembled in about an hour, to reduce down-time.

During development, the suction from a blower was used to run the gasifier. Measurements were necessary to assess the performance of the system. Hence the flow rate, pressures and temperatures at several selected locations were continuously monitored. To determine gas quality, the commonly used Orsat apparatus was time consuming; therefore, the gas, when not being used in the engine, was flared in a burner in the diffusion-flame mode and the flame temperature was continuously measured and used as a direct indication of gas quality. When the gasifier was connected to the engine, the pump performance in terms of its rotational speed (rpm) and load (measured as the flow rate at known pumping head) was taken as a measure of the gas quality and was correlated with the measurement of composition at selected power levels.

Functionally, the reactor consists of a fuel container, air-intake arrangement, throat (hearth), reduction zone, grate and gas-offtake system. The gas passes through a cyclone, a cooler, and a fabric filter before going into the engine. In the earlier prototypes, there were no cyclones and only the coolers and filters were used. The cyclone was introduced for the first time in the fourth prototype.

THE FUEL CHAMBER

All reactors have a fuel chamber that stores wood chips deposited therein by gravity, as in the present case, or by gravity aided by vibration. The fuel container should be able to condense the moisture liberated from the wood chips and drain it out of the reactor.

The size of the container depends on the number of hours the gasifier is expected to run continuously and on the demand for wood chips, which is about 3.5 kilograms (kg) per hour for a 3.7-kW engine. Initially, a four to eight-hour supply was provided, which required 14 to 28 kg of fuel and a container of 0.04 to 0.08 m^3 volume. The first phase used a container volume of 0.14 m^3. The volume was lowered to 0.04 m^3 in Prototype I (Figure 1). It became 0.16 m^3 in Prototype II (Figure 2) because of the availability of 200-liter drums at extremely low prices. In Prototype III (Figure 3) the volume was higher at 0.2 m^3. The total weight of the different prototypes varied from 45 to 80 kg. These were considered very heavy for field operations and it was therefore decided that the weight had to be reduced substantially. The question

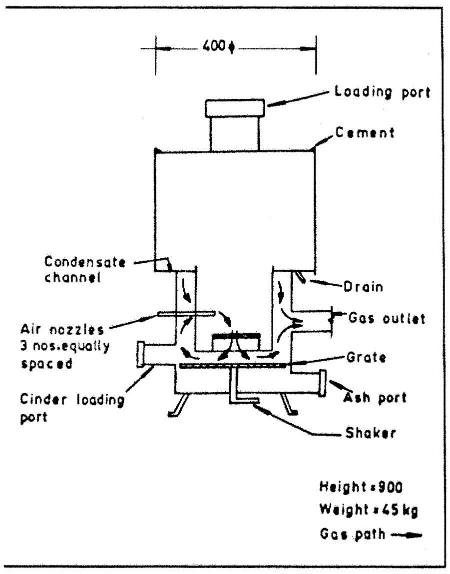


Figure 1. Prototype I (PI) (all dimensions are in mm).

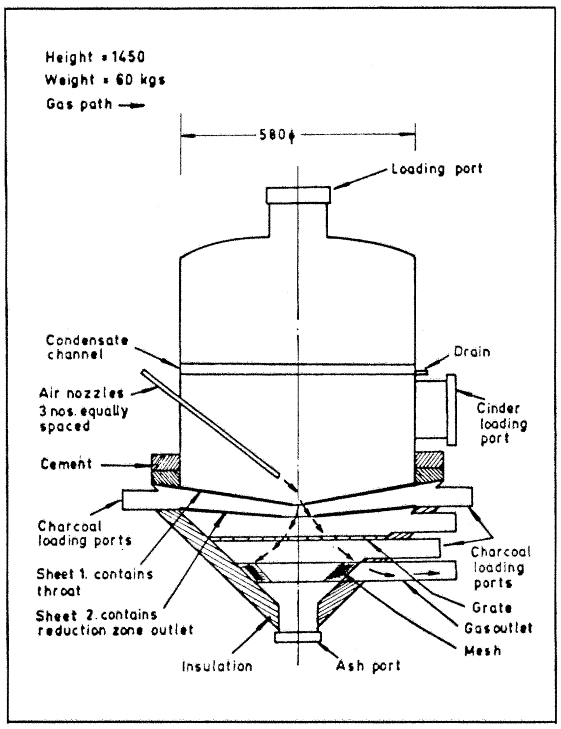


Figure 2. Prototype II (PII) (all dimensions are in mm).

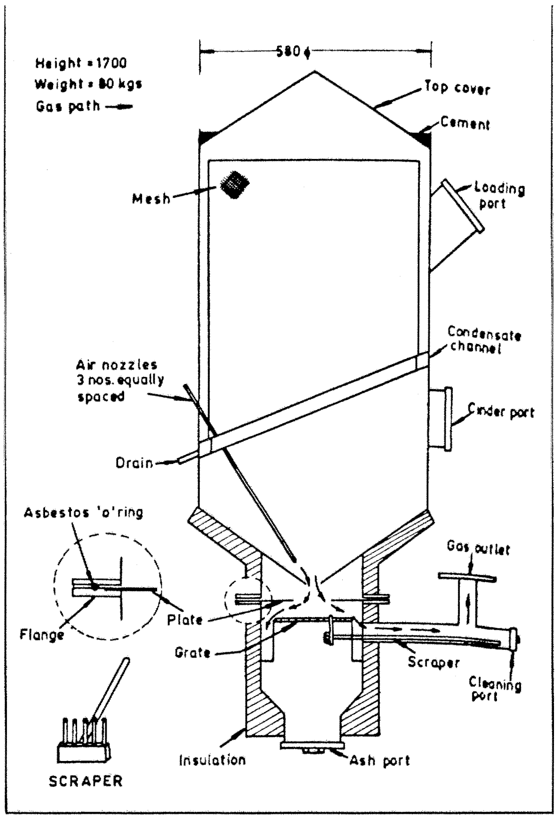


Figure 3. Prototype III (PIII) (all dimensions are in mm).

of the number of hours of continuous operation was reviewed, and it was found that water in most wells in Karnataka could be pumped in two to three hours at a pumping rate of .01 m^3 per second. Consequently, it was decided to provide for a substantially lower volume. Prototype IV (Figure 4) has a volume of 0.04 m^3 with a diameter of 0.2 m and a height of about 1.0 m. The increased height allows for a better flow of wood chips.

Concerning the other requirement of removal of moisture from wood chips, in Prototype I, a drain was provided, and in Prototypes II and III, channels to drain condensed moisture were provided. In Prototype III, the scheme worked well for a while. However, during loading, wood chips fell into the channel and blocked it. This was prevented by using a mesh. Still, once every twenty hours of operation, the channel would get clogged with tar and cause excessive moisture in the gasifier and deterioration in performance.

In Prototype IV this problem was successfully overcome by a method that has not been used in any other design known to the authors. The arrangement consists of a water seal at the top of the container, the water being replenished once every an hour or so (Figure 5). The vapors, released from the wood chips as they approach the hot hearth zone, condense on the conical top (where the temperature does not exceed 55°C) and drain out of the reactor. Thus, even if relatively moist wood chips are used, they do not pose serious problems during operation.

Another feature new to Prototype IV is somewhat like the arrangement in the Imbert reactor design (1), in which hot gases are let out at a good height above the hearth. The outlet is above the air nozzles in the present design. Consequently, most of the wood chips in the container are exposed to the heat from the hot gases passing by in the outer shell, which enables effective drying of the chips. Conduction upwards along the walls permits a higher temperature zone, extending to the outer water channel, shown in Figure 4, where the shell is being cooled. Any condensation is possible only above the level of the channel. The complementary effects of providing a cool upper zone and a hot lower zone encourage rapid condensation to take place in the upper portion only, from which the condensate can easily be drained. This ensures satisfactory charring up to the air-nozzle entry levels, and the operation of the reactor becomes very reliable. Figure 6 summarizes the dimensions and the weights of the various prototypes developed.

LOADING OF WOOD CHIPS

Loading is done through the top cap in Prototypes I, II and IV, and through the side cap in Prototype III. To prevent wood chips from getting into the water channel, the top cap in Prototype IV is replaced by a hopper while loading. The entire loading operation in this last prototype does not take more than two minutes. During loading it is important to ensure that there are no stones, mud or other extraneous matter mixed with the wood chips. If these find their way downwards to the throat region, the reactor will produce noncombustible gas, but will have a good combustion zone near the throat, indicating blockage of the throat.

AIR INTAKE ARRANGEMENT

The air-inlet pipes were horizontally located in the early version but were introduced at an angle in the later prototypes to help visual examination of the combustion zone.

In the early versions the ratio of total air inlet-area to throat area was fixed at about 12 percent. According to the SERI report, good performance has been obtained for values ranging from three to 14 percent. Investigation of the pressure drop showed that the air-inlet line drop was about 20 mm wetgrams (w.g.) in a total drop of 90 mm w.g. It looked as though the drop across the air inlets was significant. It was decided to reduce the pressure drop across the air-inlet significantly by raising the air inlet-area by 50 percent. Instead of three air-inlet pipes of 8 mm inner diameter (ID), a similar number of pipes of 9.5 mm ID were used. This reduced the pressure drop to about half its original value because the drop varies as the square of the velocity. The velocity of the air entering the reactor is about 10 m/s in Prototype IV.

In Prototype IV the height location of the air-inlets is 56 mm and corresponds to a throat diameter of 35 mm. The air-inlet opening-circle diameter is 80 mm, or about twice the throat diameter.

THE REDUCTION ZONE

The reduction zone is immediately downstream from the throat and is critical to the successful performance of the reactor.

In Prototype I, the throat diameter was 40 mm based on the considerations of hearth loading. Later, the tests showed that better performance could be expected with a reduced throat diameter, particularly from the point of view of eliminating tar. Prototype I was run with both 40-mm and 35-mm diameter throats. Prototype II used a 35 mm throat. However, in Prototype III, experiments were conducted with throats of 35 mm and 30 mm diameters. One of the serious problems faced in prototypes up to III was the presence of semi-charred wood pieces in the reduction zone, sometimes in spite of care taken to initially load the charcoal up to and well over the air nozzles. This in part accounted for the tar seen in the gas stream. It was inferred

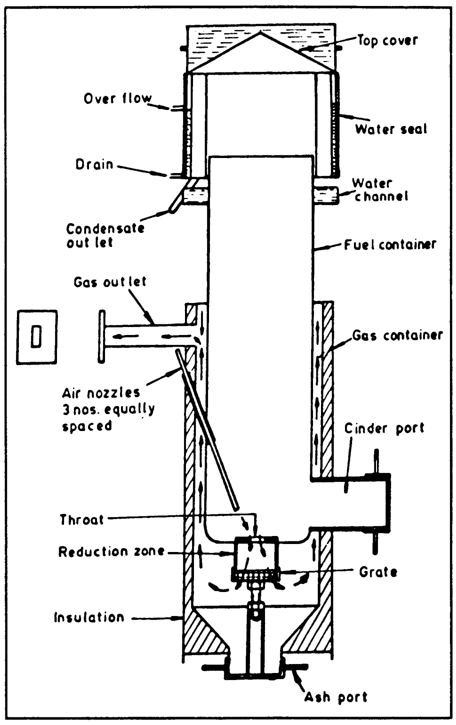
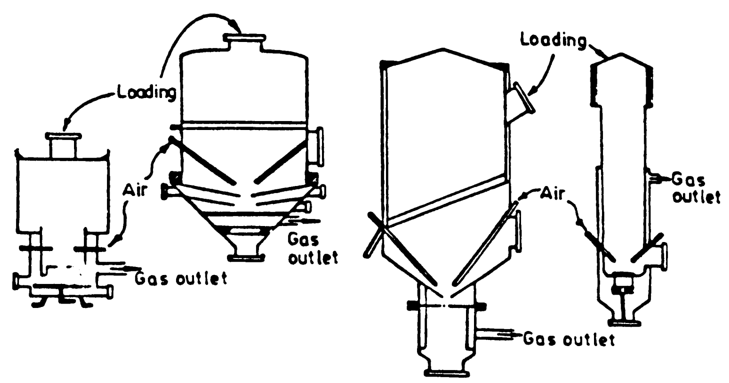


Figure 4. Prototype IV (PIV) (all dimensions are in mm).



	P I	P II	P III	P IV
Max. diameter, mm	400	580	580	235
Overall height, mm	1000 (1700)	1600	1700	1200
Weight, kg	40 (50)	60	80	35

Figure 6. The schematic of various systems, their dimensions and weights. Figures in brackets are for original version of PI before height reduction.

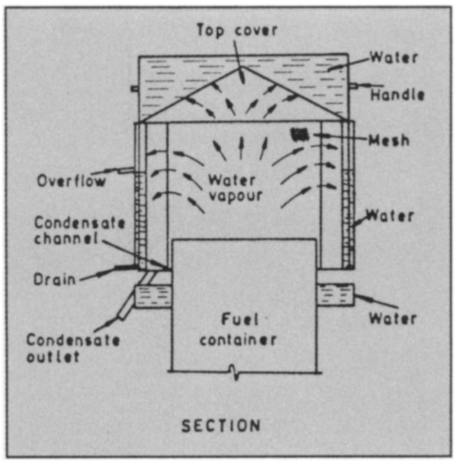


Figure 5. The water seal.

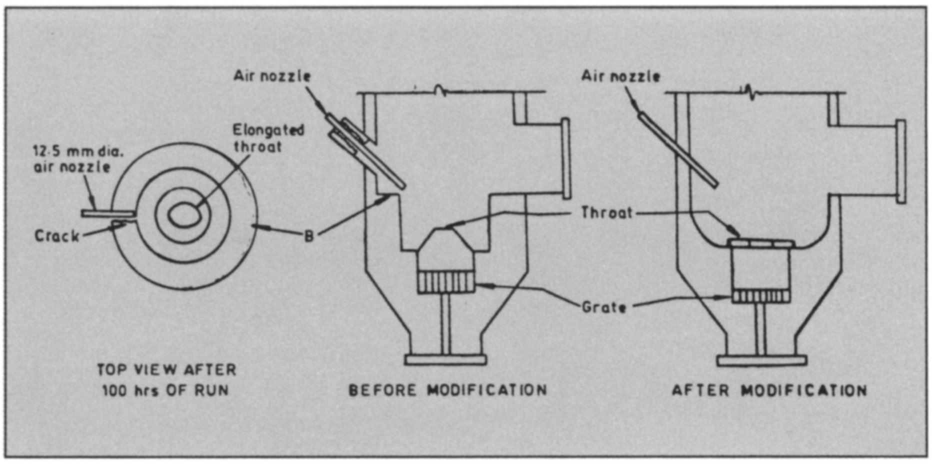


Figure 7. Prototype IV (PIV) with modification.

that some pieces of wood passed through the combustion zone before getting fully charred. This could also account for the occasional bad runs as the reduction zone becomes ineffective. Such problems have been overcome in Prototype IV, where the hot gases from the reactor are allowed to dry and char the wood pieces. Experimental runs with Prototype IV have had excellent results—no tar and only some fine dust with throats of diameters 30, 35 and 40 mm—whereas Prototype III showed good results only for a 30-mm throat. The inference that can be drawn is that if the chips are properly charred before entering the combustion zone, the performance is less sensitive to throat dimensions below 40 mm. The reduction zone volume of the first prototype was 320 cm^3 and that of the others about 250 cm^3. The residence time computed on the basis of the reduction-zone volume/volumetric flow rate works out to about 25 milliseconds in the first three prototypes and about 20 milliseconds for the fourth.

In the fourth prototype, it was found that after about 100 hours of operation the throat made of AISI-304 stainless steel had enlarged from 30-mm diameter to an elongated hole of 40-mm. At location (B) in Figure 7, there were also cracks close to the air-entry point. It was inferred that the proximity of the air nozzles must have caused high temperatures, resulting in high local thermal stresses leading to the cracks. The enormous increase in the area of the throat and its elongated shape were due also to the different sizes of the air-inlets used in those tests, i.e., one nozzle of 12.5-mm ID and two of 8-mm ID. Moreover, the presence of the char close to the metal surface at temperatures above 1,200°C might have caused diffusion of carbon into the metal, lowering its melting point. Therefore, the design was altered to that shown in Figure 7, which reduced the number of welds required. The stainless steel throat plate is simply located over the hearth, which facilitates easy replacement. Ash is expected to get deposited around the region and help in sealing against leakage. Details pertaining to the four prototypes are summarized in the Table.

GRATE AND ASH-REMOVAL SYSTEM

Several attempts were made to improve the ash-removal system. In the prototypes up to Prototype III, grates were made of cast iron with a spacing of about five mm between grate bars. In Prototypes I and II, vibrating the grate, using engine excitation, helped to move the ash downwards. In Prototype III, experiments showed that a semicharred mass was more prevalent in the reduction zone when vibration was used. Both in Prototypes I and II, the ash was sometimes found lumped together with a tar-like substance downstream from the throat. In Prototype III, a claw-like device was used to clean out the lumps of ash and allow the reduction zone to be replenished with fresh charcoal. In fact, it was very effective in ensuring that the system functioned normally whenever minor problems of gas quality arose.

Table. The hearth parameters (*figures in brackets indicate changes made).

SERI Reference No.		Prototypes				SERI Recommendation
		I	II	III	IV	
1.	d_h-throat diameter, mm	40(35)	35	35(30) (40)	30(35)	60 (lowest)
2.	d_a-air nozzle opening circle diameter, mm	110	96	96	100	
3.	d_r-reduction zone outlet diameter, mm	100	88	88	75	
4.	h-air nozzle opening circle height above throat, mm	64	56	56	56	
5.	h_1-reduction zone opening height below throat, mm	40	40	40	30	
6.	h_2-grate height below reduction zone opening, mm	40	40	40	60	
7.	air nozzle diameter mm	7	7	7(7,12.5)	9.5	
8.	no. of air nozzles	3	3	3(2,1)	3	
9.	(area of air nozzles 100/area of throat)	9.2(12)	12.0	12.0 (28.3)	30.0 (17.0)	3–10
10.	reduction zone volume cm^3	320	245	245 (237)	250 (257)	
11.	nominal gas flow rate m^3/sec	.004	.004	.004 (.003)	.003	
12.	B_h-ratio of nominal flow rate to smallest passage area Nm^3/cm^2	1.1	1.5	1.5 (1.5)	1.5 (1.9)	0.4–0.9
13.	t-residence time, milliseconds	24	19	19 (24)	21 (21)	500

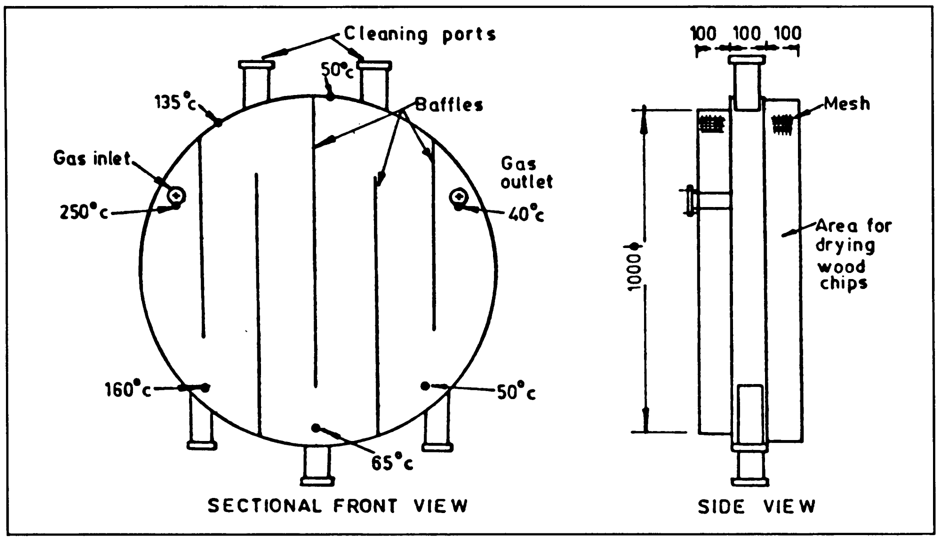


Figure 8. Baffled cooler (all dimensions are in mm). Temperatures marked are for PIV steady operating conditions.

In Prototype IV, the design of the grate was completely changed and the cleaning device was no longer necessary. The grate was introduced from the bottom screw cap and, at the end of each run, it was unscrewed to remove the ash and charcoal fines. This way the gases follow a radial exit through the grate and then move upwards. Because the velocities in the annular space are lower than one m/s, most of the particles larger than 100 μm do not get carried by the gas and are retained in the reactor itself, the process being facilitated by the sudden upward turn in the gas path.

THE CYCLONE

The cyclone has been designed following standard practices (4). Its inlet velocity at the nominal flow is 15 m/s and the dust collection efficiency is estimated to exceed 95 percent at nominal flow. The cyclone inlet temperature is about 400 to 450°C and the exit temperature 250°C. The cyclone collects about 6 g/hr of dust on the average.

THE COOLER

The cooler, a new design developed after earlier efforts, is a baffle-type heat exchanger with inside velocities not exceeding 0.3 m/s; the temperatures at different baffle-entry points are shown on Figure 8. As can be noticed, the largest drop in temperature occurs in the first two passes and this amounts to as much as 150°C. The subsequent drop of less than 40°C requires the next four passes. The thickness of the sheet is 4.6 mm.

The newest version of the cooler (Figure 9) is based on a 0.8-mm stainless sheet and is yet to be tested. The use of the thin sheet and the expected higher velocities (three times the previous value) are expected to provide better heat transfer and therefore a good cooling effect. The use of a water seal improves heat transfer through water vaporization, and simplifies the construction and cleaning of the system.

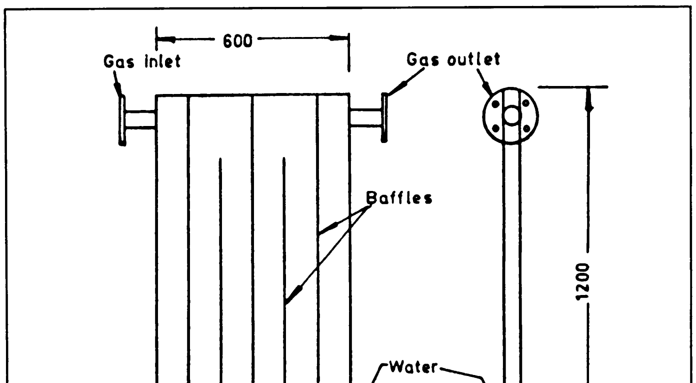


Figure 9. The new cooler with water seal (all dimensions are in mm).

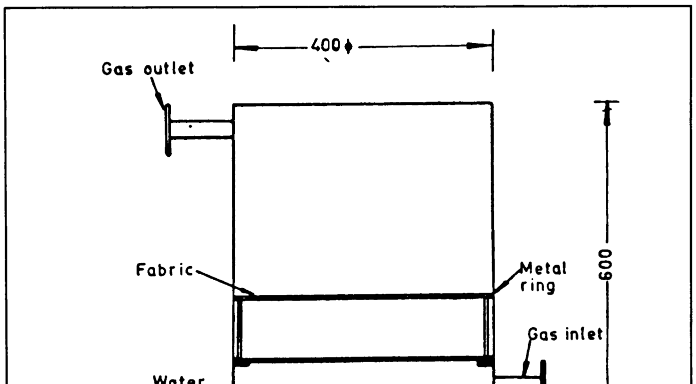


Figure 10. Fabric filter (all dimensions are in mm).

FABRIC FILTER

Recommendations on fine dust-cleaning systems (5) seem to indicate that a fabric filter (Figure 10) is essential for fine dust (of less than 5 μm). Velocities should be low at the filter (.03 to .05 cm/s), which requires a large cross-sectional area. This requirement could be combined with another one for a large volume to act as an acoustic isolator between the engine and the gasifier. Hence, a cylindrical vessel of 0.07 m^3 capacity has been fitted with two layers of fabric filter material. The gas passing through this system should be almost dust free; the system is yet to be fabricated and tested.

OPERATION OF THE REACTOR

In all the prototypes, the reactors were filled with charcoal up to a little above the air-entry points, with slightly smaller pieces for the reduction zone. The lighting processes, however, were different for the four prototypes. In systems I to III, specially prepared cinders were loaded near the hearth, either from the bottom or from the top, and air was either blown in or drawn out depending on the location. In some tests wood was loaded immediately after the cinders and, in others, after the reduction zone became sufficiently hot. In the latter situation, a few explosions were experienced, particularly with Prototype III immediately after closing the cap. However, when wood was loaded along with charcoal there were no problems.

However, the most recent starting scheme consists of loading the charcoal first and then the wood chips, applying suction to the system by using an electric blower, and holding a burning kerosene wick near the air-inlet nozzles for no more than 30 seconds.

When Prototype IV is running under steady conditions for a nominal flow rate of 3.2 g/s, the various system parameters are as given below (with deviations referring to fluctuations during the run).

Temperature:	
Combustion zone	1,300–1,400°C
Throat temperature	1,000–1,200°C
Reduction zone	900–1,000°C
Gas outlet	550–600°C
Cyclone outlet	250–600°C
Cooler outlet	<45°C

Pressure drop:	
Total system	75 ± 10 mm (w.g.)
Across the reactor	55 ± 10 mm (w.g.)
Across the cooler	12 ± 5 mm (w.g.)
Across the cyclone	6 ± 2 mm (w.g.)
Across air inlet	20 ± 5 mm (w.g.)

Gas flow rate 3.2 ± .2/s

An estimate of the pressure drop across the cyclone by Strauss (5) roughly matches what is observed—8.0 mm w.g. for nominal conditions. The pressure drop across the cooler was estimated at 0.10 mm w.g., whereas the measured value is 12 mm w.g. The discrepancy may be due to the continuous resistance that occurs when the hot fine pieces of cinders move down the system in jerks. A maximum total pressure drop across the air inlet of about 85 mm w.g. seems reasonable. The total pressure drop should be less than 100 mm w.g. (including the drop across the fabric filter) to match the engine suction capabilities.

Implementation of these concepts produced a prototype that is reliable and operates smoothly. The problem of the throat blockage due to inadvertently introduced matter like stones and clay into the system remains. However, this can be avoided when loading the wood. Measurements for tar and dust showed that the amount of tar, if any, is much below detection limits (<10 ppm) and the dust is about 6 g/hr for prototype IV. On Prototypes I and II, the tar was of the order of 1,000 ppm, and dust was not as significant as it was in Prototype III.

EXPERIENCE WITH ENGINE RUNS

While tests with Prototype I and earlier designs were conducted using a diesel-engine pump set, the tests with Prototypes II–IV have used a gasoline/kerosene-engine pump set. For about the same cost as a diesel engine pump set, one can buy a gasoline/kerosene-engine pump set that can be run entirely on gas, though the power output would be reduced by about 35 to 40 percent. Except for ignition, which requires gasoline, one does not need petroleum to run the system. Thus, even if the power output is reduced, the dependence on petroleum fuels will be minimal.

The engine used was a Villiers 4-stroke, 3.7-kW engine of 250 cm^3 displacement at a rated speed of 3,250 reverberations per minute (rpm). The engine starts on gasoline and runs on kerosene. The average fuel consumption is about one kg/hr. If the governor mechanism is disengaged the engine speed can be increased to 4,100 rpm.

The gas line has a side branch with a gate valve to allow air to be mixed with the fuel. The normal stoichiometric composition of the fuel and air is equal amounts by volume. The mixture is directly sent to the air inlet of the carburetor.

There were difficulties experienced during the engine switch to gas. They were traced to impedence matching between the engine and the fuel lines; a large volume capacitance was added upstream of the inlet to the engine, which resulted in smooth switchovers. In some experiments the container acting as a capacitance device was filled with metal turnings, and in others with organic fibers that filtered the fine dust. They were not very effective, however, and the reduction in volume caused engine-speed variations. In the event of a shut-down the pressure waves would clog the air inlets with tar and the machine would require cleaning before restarting.

When the entire system was cleaned and started anew, the engine was observed to run smoothly for hours on end without any problems; but starting with unclean elements sometimes resulted in lower performance. At optimum operating conditions the engine reached 2,800 rpm. At average operating conditions the speed fluctuated between 2,600 and 2,700 rpm. At a mean of 2,650 rpm, the power output corresponded to $(2.650/3.250)^3 \times 100 = 54$ percent of the rated power on gasoline/kerosene. Under these conditions, the water pumping rate was .008 m^3/s (28.8 m^3/hr) at a head of 10 m of water (0.1 hp).

In order to improve the system performance, the pump was uncoupled from the engine and reconnected, using a pulley-belt drive. The pulley ratio was so adjusted that the engine could be run at speeds higher than previously. One started with no load on the engine, i.e., no flow of water, and increased the load slowly, which resulted in the engine demanding a higher flow of gas input. The performance of the gasifier usually became better with larger flow rates. The ratio of the speeds of the engine and the pump was set at 1.25 and 1.3 in two different trials. The engine ran at 3,300–3,400 rpm and the pump at 2,700–2,800 rpm, corresponding to a power output of 62 percent of the rated power. To produce wood chips from logs a cutter was attached to a second shaft so that one could transfer the load from the pump to the cutter when required. Trials with the cutting device were successful, but more experiments are necessary to decide on its usefulness.

CONCLUSION

A description of the morphology of the four prototypes in various stages of development has been presented. It is claimed that the final version meets most requirements, and experimental data supports this claim. Two features—a top cap using a water seal and a high gas offtake point—help to obtain good reactor performance. The next task is to test the system in a field environment and examine its potential for satisfactory operation.

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6. The results presented here are the outcome of a project on wood gas generators for engines of less than 10 hp financed and administered by the Karnataka State Council for Science and Technology, Indian Institute of Science, Bangalore. The authors are grateful for the support provided.

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