Biomass Gasification: Field Monitoring Results

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Part II

ABSTRACT

This paper continues the review of gasifier monitoring results by presenting details from units in Vanuatu and in Mali.

A presentation of all the data in a summarised form is made and the advantages and dangers of installation evaluation based on data in such a form are highlighted. Values, typical of gasifiers in the field, are presented for many of the 19 parameters used in these papers. It is concluded that gasifiers (generally) work well in the field, but must be tailored not only to the needs of the energy demand, but also to the needs of the feedstock. The disposal of contaminated waste water streams is a continuing problem in Developing Countries, in spite of suitable technology being available in Developed Countries to render the waste streams safe. In summary, the problems no longer lie with the technology of gasification per se, they are now associated with its implementation.

Key words: biomass gasification, Developing Countries, gasifier–engine performance, gasifier–engine system, Mali, rice husk, Vanuatu, wood.

INTRODUCTION

In Part I of this paper, the methodology of field monitoring gasifiers was explained1 and two actual cases were reviewed; a gasifier in Burundi2

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(which was characterised by a poor match of technology to feed material coupled with sloppy installation engineering) and a gasifier in the Seychelles (which, although it performed well, also performed below specification and had a number of small, but annoying, design faults). In Part II, two further monitorings will be covered, one in Vanuatu in the South Pacific and the other of a unit in Mali. Finally, the paper presents the conclusions that can be drawn from an assessment of the material presented in both Parts I and II.

VANUATU

The installation was a 25-kW downdraft, wood-fuelled gasifier. It was installed immediately prior to the monitoring and so the hours worked and electricity produced totals were effectively zero. The unit performed well, yielding gas with a good calorific value and having acceptable tar and dust contents. It performed slightly below the specified fuel consumption and system efficiency from a number of minor design faults. There was also a minor problem with the nature of the condensate and its disposal. The economics of the plant were good, although they would have been better if the plant had been used to capacity.

The unit was installed at a high school situated approximately 56 km from Port Vila on the island of Efate in Vanuatu. The high school has performed extensive experiments with a home-made gasifier in the past but suffered problems in obtaining satisfactory cleaning of the gas.

Prior to the installation of the gasifier, the school drew its power from a three-cylinder Lister diesel generating set, able to deliver approxi-
mately 25 kW. During the early evening, the total power demand of the school is around 20 kW, but during the day the load is considerably lower and often consists solely of 3–4 kW drawn by a water pump. The gasifier is coupled to a 25-kW full-gas generator set and the whole unit is owned by the Government of Vanuatu.

A schematic diagram of the installation is shown in Fig. 1 and can be broken down into four distinct parts: the fuel harvesting, transportation, storage and feeding system; the gasifier itself; the gas cleaning and cooling section; and the engine–generator set. The fuel handling equipment consisted of two chain saws for felling, a tractor and trailer for transportation (approximately 4 km), a storage shed arranged to take the hot air from the gas cooler and the engine radiator to facilitate drying. Gasifier fuelling involved using a winch to raise the wood from ground level to the fuel feeding platform and then manually loading it into the gasifier via a twin flap sluice.

The gasifier is a traditional style downdraft gasifier, having five refractory steel tuyeres and a double-walled arrangement of the bunker, oxidation and reduction zones for the gas outlet stream, in order to provide better insulation for the hottest parts of the gasifier. There is no provision for additional tar cracking.

The fuel bed sits on a manually rotated iron bar-type grate, through which ash falls into the ash compartment. Ash can be removed from the ash pan through a hatch when the plant is not in operation.

Start-up draft is created by an electric fan, the resultant (dirty) producer gas being flared off. The quality of the gas being flared is monitored by a visual examination of the flame colour. When it is determined as being of sufficient quality, the fan is turned off and by-passed and the engine is started. Start-up time is between 5 and 15 min. The manufacturer’s specifications give the maximum gas production as 120 Nm$^3$ h$^{-1}$ at a gas heating value of 4.8 MJ Nm$^{-3}$. The specified efficiency at full load is between 1.15 kg wood kWh$^{-1}$ (15% moisture content, dry weight basis) and 1.40 kg wood kWh$^{-1}$ (25% moisture content, dry weight basis).

The gas cleaning section consists of an insulated cyclone, a finned cooler, an insulated baffle filter, a bag filter and a bag cooler. The cyclone is situated in the hot gasifier outlet stream and is equipped with an extra whirl chamber for optimum particle collection efficiency. The finned cooler is placed between the cyclone and the baffle filter to avoid damage to the filter by too high gas temperatures. The insulated baffle or sheet filter is a simple impingement separator with removable covers for cleaning. The bag or glass fibre filter consists of a number of glass fibre filter bags in a container. This ‘filter house’ is well insulated in order to
keep the temperature above 100°C and so avoid water condensation. The bags can be cleaned by periodic vibration of the bag suspension frame. In order to safeguard the bags, the inlet temperature is monitored and not allowed to be above 220°C. The house is fitted with a tap for the removal of condensates.

The gas cooler is a forced convection heat exchanger powered by an electric fan, condensates being easily drained off using the tap provided. The heated air can be directed to the wood storage shed to assist with drying. Forced convection was used for lowering the producer gas temperature since (a) it increased the engine power output by producing a cooler gas with more energy per unit volume and (b) the extra cooling leads to more water vapour condensing out, which also improves the gas heating value. The generating set comprises a Ford gas engine coupled to a Stamford generator.

The engine is a six-cylinder in-line, 6.2-litre, water-cooled, four-stroke Ford Power Torque gas engine, type SN 16G provided with an electronic speed controller (Heinzmann) and electronic ignition. The engine is started by a battery-powered starter motor, the battery for which is recharged using a separate battery charger. The secondary air is preheated by the engine’s radiator. The power generation is by a directly coupled Stamford brushless, three-phase, AC generator producing 35 kVA (28 kW) with an efficiency of 0.868 at full load. Overall, the unit is specified as having a maximum power output of 25 kW (continuous) or 27.5 kW (peak), consuming between 174 kg wood (15% moisture, dry weight basis) and 210 kg wood (25% moisture, dry weight basis) at full load every hour.

To overcome the potential difficulties of working at very low loads (low gas flows through the gasifier allowing severe tar breakthrough with resultant risks of damage to the engine), the unit was equipped with a 15 kW ballast load set up in such a way as to avoid the load ever falling below 15 kW (60% of full load). As in the cases of Burundi and the Seychelles, it became apparent during the course of the monitoring that a number of design and operational changes were necessary to overcome shortcomings.

(1) To avoid condensate entering the main gas pipe and thereby running a risk of damaging, or even ruining, the engine, it was necessary to empty the condensate tank after the baghouse filter every 2 h. Since the gasifier had been constructed so as to run for 6 h without refuelling, it seemed necessary to enlarge the dimensions of the condensate tank so that it too could operate for 6 h without attention.
(2) One of the drains was found to be without a double safety valve system.

(3) After shutdown of the system, the start-up fan, because of its low position, becomes filled with condensate. This will reduce its working lifetime and so its position must be altered (made higher).

(4) The position of the condensate drain taps for the baghouse filter and the gas cooler must be changed since they are difficult to operate owing to the surrounding high-temperature pipework.

(5) The secondary air is preheated by the engine’s radiator up to 50°C which is too high and leads to a drop in the engine’s output.

(6) The safety filter for the engine has no pressure drop indicator and was very difficult to replace.

(7) The manometer for the venturi is on the baghouse filter wall where it gets hot. Thus it will deteriorate faster than usual and the readings will be unreliable because of density changes. In addition, the whole venturi needed to be rotated by 90° because in its old position, the connections gradually fill with condensate.

(8) A great deal of heat is lost from the gas cooler air and engine radiator air before it reaches the drying shed. A hot air duct is a necessity.

(9) Increased drying capacity could be obtained by equipping the drying shed with racks.

(10) The specified manometers had been damaged during transportation and had been replaced by PVC hoses. There is a danger they will quickly become opaque and unreadable.

(11) The control system lacks a shut down device for high lubricating oil temperature.

(12) The fuel feeding platform required a safety rail.

(13) It is noted that the listed defects are oversights in the initial plant rather than design faults. It is believed that they have now, for the most part, been satisfactorily rectified.

Performance characteristics

Gasifier conversion efficiency

The gasifier had an efficiency of 77% with dry wood (approximately 17% moisture, dry weight basis) and an efficiency of 72% with wet wood (approximately 28% moisture, dry weight basis). These efficiencies were almost invariant with load. In all cases the resultant fuel consumption rate was higher than the manufacturer’s specifications. (Recorded
figures: full load 17% moisture, 1·33 kg kWh$^{-1}$; full load, 28% moisture 1·69 kg kWh$^{-1}$.)

Gasifier outlet temperature
At 60% load with dry wood, the temperature varied between 180 and 380°C. In a few other runs, it exceeded 400°C (the maximum recordable on the temperature measuring device used).

Dust and tar contents of the raw gas
For reasons of plant layout, it proved impossible to determine these parameters.

Pressure drop (gasifier)
The pressure drop over the bunker varied from 1 to 4 cm water at 60% load to between 3 and 6 cm water at full load. The pressure drop across the reduction zone was about 2 cm water at all loads. These values are all low and hence it can be concluded that the wood presents no pressure drop problems.

Ash characteristics
The ash was not characterised owing to lack of time. However, given that the fuel was wood, the estimated ash fusion temperature should be in excess of 1400°C. Hence, the lack of clinker formation was not surprising.

Performance of the gas conditioning system
The pressure drop over the baffle filter was effectively zero, but the pressure drop over the bag filter rose steadily, at a rate of about 7 cm water per day. On cleaning at a pressure drop of 23 cm water, the observed pressure drop fell to 3 cm water and then proceeded to climb as before. In all cases, the gas temperature was reduced to about 44°C. It may be concluded that the gas cooling system works well.

Dust and tar content (clean gas)
The dust content of the clean gas was negligible (less than 1 mg Nm$^{-3}$). Given a standard of cleanliness of 50 mg Nm$^{-3}$, this indicates that the filter system gives extremely good dust removal. The tar content was found to be around 15 mg Nm$^{-3}$, indicating, with a criterion of below 150 mg Nm$^{-3}$, extremely good tar cleaning abilities. (It should be remembered that good quality charcoal releases very little tar on heating.)
Gas composition
Gas analyses, whilst showing nothing abnormal, clearly indicated the high dependency of the gas composition on the fuel and process conditions. A rather high oxygen level was found in the gas (between 2 and 4.5%) which can only partially be explained by sampling and measuring errors or leaks.

Gas calorific value
The gas lower heating values were calculated from Orsat analyses. The gas lower heating values were found to vary from 4.4 to 4.8 MJ Nm\(^{-3}\) at all loads. The values were found to be stable during continuous operation and were not found to be functions of fuel moisture content.

Engine/generator efficiency
Overall efficiencies for the set were determined at 17% at 60% load and 21.4% at full load. No effect of moisture content on efficiency could be determined.

Engine fouling
No evidence of engine fouling was found and engine performance was satisfactory.

Engine exhaust gas composition
The exhaust gas measurements showed low carbon monoxide concentrations (below 0.1%) but relatively high oxygen concentrations (2.8% at 15 kW). The carbon monoxide data indicated that combustion was almost complete and, when considered with the oxygen data, further indicated that the gas/air setting was generally properly adjusted.

Engine lubrication oil analyses
Oil analyses indicated that the oil cooler was subject to wear (high copper content), probably caused by acid components in the producer gas. No other evidence of high wear could be determined from the oil samples.

Overall system efficiency
The overall efficiency of the system was between 12 and 13% at 60% load and between 14 and 16.8% at full load, the lower figures being for wet fuel (28% moisture, dry weight basis), whilst the higher figures are for dry wood (17% moisture, dry weight basis). The maximum net power output on wet wood was 27.5 kW, using dry wood it was between 30 and 32 kW.

Condensate analysis
When dry wood was used as fuel, almost no condensate could be drained off, the moisture being carried as water vapour in the producer gas. Wet
wood yielded considerably more condensate for which the method of disposal was emptying it into a sump. Analysis of the condensate showed the presence of a number of non-biodegradable components such as benz(a)anthracene and benz(a)pyrene. Given that the operators work bare-handed with this condensate, there is a serious health risk evident.

**Carbon monoxide emissions**
Carbon monoxide measurements in and around the plant showed a maximum carbon monoxide concentration of 5 ppm. No traceable carbon monoxide emissions were produced by the reactor.

**Economics**
The gasifier was unable, even with a load factor of one, to produce electricity cheaper than the market price. However, the power produced is almost as cheap as commercial electricity.

**Conclusions**
The gasifier ran well and in accordance with the manufacturer’s specifications except with respect to the wood consumption. The results were good compared with those from gasifiers of a similar design and corresponded well to the operators’ expectations.

**MALI**
The last installation to be reviewed is perhaps the most interesting. Something of a legend in gasification circles, it is a rice-husk gasifier which has been working satisfactorily for the last 20 years.

The plant was built in 1967 by personnel from the People’s Republic of China. It is an open-core (stratified downdraft), rice-husk gasifier. Until 1984, when a major overhaul took place, it had worked around 50,000 h and generated 2.8 GWh. From 1984 until the monitoring in 1986, it had worked 5000 h and produced 400 MWh. The unit was characterised by an absence of standard operating procedures, poor dust and tar cleaning, poor mixing of air at the inlet manifold and problems with the nature of condensate and its disposal. However, the pressure drop across the whole unit and in sections was acceptable. It produced gas of a high calorific value, had been working for 20 years and the client was satisfied with its performance. Economically the plant was also a success.

The installation lies about 415 km north-east of the capital of Mali, Bamoko, not far from Niono. It is one of three rice-husk gasifiers in the area, all of which are owned by the Office du Niger (a quasi-governmental organisation under the Ministry of Agriculture) for electricity production
at their rice processing factories. The gasifier is connected to a 160-kW full-gas generator set. Additional (alternative) power sources in the rice mill are two diesel generator sets of 140 and 40 kW. A schematic diagram of the unit is shown in Fig. 2.

The unit can be broken down into easily defined sections: the fuel preparation equipment, the gasifier itself, the gas conditioning equipment and the engine-generator set. The fuel transportation, storage and feeding equipment is different from that in the previous gasifiers because here the material to be gasified is very different. There is only a very limited buffer for rice husk at the rice processing factory so processed rice husk is continuously blown into a transport pipeline. This pipeline can either take husk directly to the gasifier house or to the bunkers. From the bunkers excess rice husk is taken by tractor to the fields for dumping. Before entering the gasifier building, the rice husk passes through a cyclone to remove dust (which is fed to the bunkers for dumping) and then passes into a feed hopper, ready to be fed batchwise into the gasifier.

The gasifier is an open-core, downdraft, fixed-bed gasifier. It consumes between 300 and 320 kg rice husk per hour when meeting an average net load of 80 kW. This represents about half the rice husks which become available when the factory is operating at this level of power consumption (2500–3000 kg paddy h⁻¹). The lower parts of the gasifier are surrounded by a cooling water jacket. The fuel bed sits on a

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**Fig. 2.** Gasification installation in Mali. 1, Feed hopper; 2, rice-husk elevator; 3, gasifier, 4, 5, 6, gas conditioning system; 7, flare; 8, 9, engine–generator.
plain, slightly convex grate which is rotated by a variable speed motor, the ash passing through the grate into a water-sealed pit. A sludge pump at the bottom of the pit forces the ash through a pipe to a basin where it mixes with the rest of the waste water from the plant. The mixture then flows by gravity along an open sewer into an open field outside the factory.

The producer gas flows upwards between the inner and the outer chambers, on its way cooling from around 950°C to nearer 150°C through the effect of the cooling water jacket. The gas is transported solely by the suction of the engine during normal running, but for start-up an electric fan is used. Start-up can be achieved in as little as 15 min after a 24-h shutdown. During operation the operator locates the position of the burning zone by sticking a metal rod into the gasifier, allowing it to heat up, withdrawing it and looking to see where it is red hot. If the zone is found to be too high up, it is lowered by increasing the ash removal rate. The unit is about 1.9 m diameter and stands 3.4 m tall with the grate at a height of 1 m. The ash zone is usually kept at 1.6 m from the top, leaving an ash column of 0.8 m. A maximum fuel gas output of 785 m$^3$ h$^{-1}$ is specified, together with a maximum rice-husk input of 350 kg h$^{-1}$.

The gas treatment section comprises an ash flushing tube, two wet scrubbing towers and a large dry filter. The ash flushing tube contains a water spray nozzle at the top, and at the base is a water seal positioned in the waste water stream. The gas passes up through the water spray, being washed clean of dust and condensates, the water flowing with the other waste water streams into the field. The cooling action of the tower reduces the gas temperature to about 30°C. The specified water flow is 2.4 m$^3$ h$^{-1}$ and the maximum gas velocity is 6.84 m s$^{-1}$. There are two wet scrubbing towers (filter cooling towers) situated after the ash flushing tube whose purpose, rather than cooling the gas, is scrubbing it. In each tower the gas passes through two sets of filters, each equipped with a water spray nozzle and consisting of 250 plastic balls (diameter around 35 mm). As before, the towers are water sealed at the base with effluent run away to the field. (In fact the number of balls in use at this unit was considerably less than the figure indicated above. The reason for this was not apparent since there were sufficient number of spare balls available on site to make up the deficiency.) The dry filter was a large diameter (0.63 m) drum containing locally available fruits with a sponge-like open structure. It was equipped with a drain-off pipe. The engine was a six-cylinder in-line, 88.3-litre, water-cooled unit, made in the Hongyan Machine Works, China, model 6250M1. Originally a four-stroke diesel, it had been converted by the Chinese to full-gas, spark-ignition operation
by changing the cylinder heads and reducing the compression ratio. The rated output was 159 kW at 600 rpm for full gas operation. The specified average gas consumption at the maximum (12 h) rated output of 176 kW is 3 Nm$^3$ kWh$^{-1}$. The engine has uncovered valves which can easily be removed for cleaning. In practice the valves were taken out and replaced by a spare, cleaned set every week. The generator is a 160 kW three-phase model of unknown make (Hongyan?) but type TF-X13-TH. As usual, a number of shortcomings were found in the installation.

The engine governor badly needed overhauling so that the engine could work in a stable manner at loads below 60 kW and the engine also needed an automatic stop device in the event of high cooling water temperature. An engine air filter was also recommended (as will be seen, the silica content of the engine oil was rather high, indicating the potential for heightened engine wear).

**Performance characteristics**

*Gasifier conversion efficiency*

It was determined that the gasifier efficiency was 32% at a plant output of 81 kW.

*Gasifier outlet temperature*

Measured gas outlet temperatures varied from 80°C (usual) to 120°C (exceptional).

*Dust and tar content (raw gas)*

The raw gas tar and dust contents were 12.858 g Nm$^{-3}$ and 13.209 g Nm$^{-3}$, respectively. Given the usual norms of 150 mg Nm$^{-3}$ (tar) and 50 mg Nm$^{-3}$ (dust), this gas was exceptionally dirty.

*Pressure drop (gasifier)*

The pressure drop over the gasifier was around 4 cm water, irrespective of the load. This is low and so it can be concluded that in this style of gasifier, rice husk presents no real pressure drop problems.

*Ash characteristics*

In keeping with almost all rice-husk gasifiers, the ash contained a large proportion of carbon (43% dry weight basis). Fusion temperatures were in excess of 1400°C. The quantity of solid residue was approximately 0.42 kg per kg rice husks.

*Performance of gas conditioning system*

The pressure drop over the ash flushing tube and the two wet scrubber towers varied between 9 cm water at 20 kW and 13 cm water at 90 kW.
The dry filter gave rise to pressure drops of 3 cm water at 20 kW and 5 cm water at 90 kW. The temperature drop over the gas conditioning system was in all cases sufficient to reduce the gas temperature to around 30°C. This is often below the ambient air temperature.

**Dust and tar content (clean gas)**
Tar removal varied between 68 and 79% at 90 kW. Under all circumstances the tar content of the clean gas was in excess of 2.6 g Nm\(^{-3}\). Dust removal was about 98% at 90 kW. Even so, this still leaves the clean gas with a dust content of around 0.25 g Nm\(^{-3}\). In view of the norms previously detailed, this gas can still be considered very dirty. Nevertheless, the engine appeared to cope with this gas without problems although the valves and valve housings were removed at least once a week for cleaning. High levels of silicates were found in residues on the valves and inlet manifold but the long life of the engine shows that these are not giving rise to exceptional wear or related problems.

**Gas composition**
The Orsat analysis of the gas indicated that it contained high levels (7.8%–10.1%) of methane. Since the Orsat method does not distinguish between methane and other hydrocarbons, it seems likely that this anomaly can be explained as the presence of tars in the gas. The oxygen percentage was also rather high (up to 2.2% during start-up). This is only partly explicable by oxygen devolution from the warming scrubber water, sampling or measuring errors or leaks around the grate shaft. It was tentatively concluded that some of the input air was not being consumed by the gasification and was by-passing the burning zone by channelling.

**Gas calorific value**
The gas lower heating values varied between 5.5 and 6 MJ Nm\(^{-3}\) during continuous operation. The values determined were stable over long periods.

**Engine/generator efficiency**
At 20 kW and at 90 kW, the engine efficiency is 7.6% and 23.5% respectively. The low efficiency at low loads indicates the high power consumption used simply for rotation of the engine.

**Engine fouling**
The valves were observed to become sticky with tar during the course of a week’s running. So much so, that they had to be changed for a spare set and then cleaned every seven days. In addition, the engine was some-
times difficult to restart owing to insufficient oxygen concentrations in the inlet manifold to allow proper ignition. An agreed starting procedure would have helped overcome this problem.

**Engine exhaust gas composition**
Analyses showed carbon monoxide concentrations of below 0·2% and high oxygen concentrations of above 3·5% at 90 kW. The carbon monoxide results indicated that combustion was effectively complete and, considered with the oxygen level, it may be concluded that the gas/air setting was generally correct.

**Engine lubrication oil analysis**
Comparison of new and 400-h engine oil samples showed a dramatic increase in soot, iron, copper, aluminium and silica content. It was concluded that the engine was subject to considerable wear.

**Overall system efficiency**
The overall efficiency, because of the shortage of data on the gasifier efficiency, can only be determined at one power output. At 81 kW the overall efficiency was just under 8%. The engine efficiency data would indicate an overall efficiency of around 2% at very low plant loads.

**Condensate analysis**
The condensates are diluted in 46 m³ of system water and disposed of in the open field. A number of non-biodegradable components are present, such as benz(a)anthracene and benz(a)pyrene. The rate of build up of these two components was estimated as 1 kg and 3 kg per year. They are also present, at lower concentrations, in the water used for the weekly cleaning of the unit. The danger is that the operators, who have also been using diesel fuel for cleaning, are working bare-handed with this water. The diesel will have degreased their skin and so increased its absorption capacity, thus creating a hazardous situation. Tar deposits from the gasifier outlet showed the same components, but in different concentrations; there were more of the higher molecular weight hydrocarbons and less of the more volatile, more soluble phenols.

The biological oxygen demand (BOD) was 76 mg oxygen litre⁻¹ and the chemical oxygen demand (COD) was 195 mg oxygen litre⁻¹. The European standard for the BOD is 5 mg oxygen litre⁻¹, and so the condensate can be classed as severely polluted, needing to be diluted at least 25 times before discharging. The ratio of BOD to COD is 2·5, which indicates that the condensate is relatively biodegradable. Overall, frequent skin contact must be avoided and an environmentally acceptable way of condensate disposal must be found.
Carbon monoxide emissions
A small amount of carbon monoxide was sometimes released from the test burner when it was not closed during start-up. This gave rise to concentrations of between 100 and 125 ppm at 25 cm distance. At 1.5 m distance, the values were below 25 ppm. The reactor normally released no carbon monoxide. In the one case where the water seal was broken by the water being too low, the reactor acted as a combustor. This produced carbon monoxide levels of between 150 and 200 ppm at 30 cm distance from the gasifier top and 10 to 25 ppm near the unsealed base.

Economics
The installation produces electricity below the market price, but could produce electricity even cheaper were it to run for longer periods and at higher loads.

Conclusions
The reactor works as well as any rice-husk gasifier and meets the users' expectations. It is interesting to note that it seems to suffer from very few design faults compared to the other three units. Given that it is approximately ten times as old as the others, it is reasonable to conclude that the problems have been solved during the passage of time, to give a working, reliable unit.

SUMMARY
The results of each of the four monitorings described in Parts I and II of this paper are presented, in summary form, in Table 1 which is drawn up in terms of the 19 parameters used in each of the installation studies. Many of the problems highlighted in the text can be deduced from the bare facts in Table 1. Burundi worked at low gasifier efficiency and had a higher gasifier outlet temperature, implying combustion. Seychelles shows nothing really unusual. Vanuatu produces very clean gas and has a high overall efficiency. Mali produces very dirty gas (of a high heating value) and as a result suffers engine fouling and engine wear.

Without a knowledge of the units themselves and of gasification technology, false conclusions can easily be made from such a summary table.

(1) Mali has the same problems with the gasifier as Burundi had since the efficiencies are both very low. (Rice-husk gasifiers always leave a lot of carbon in the ash and so have low efficiencies.)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Burundi</th>
<th>Seychelles</th>
<th>Vanuatu</th>
<th>Mali</th>
</tr>
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<tbody>
<tr>
<td>Gasifier conversion efficiency, %</td>
<td>20-59</td>
<td>56-77</td>
<td>72-77</td>
<td>32</td>
</tr>
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<td>Gasifier outlet temperature, °C</td>
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<td>240-360</td>
<td>280-400+</td>
<td>80-120</td>
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<td>10-28</td>
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<td>20-50, 30-50</td>
<td>0-23, 44</td>
<td>12-18, 30</td>
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<td>Approx. 0</td>
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<td>15</td>
<td>2-6 g Nm⁻³</td>
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<td>Gas composition</td>
<td>CO₂ increases</td>
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<td>Normal, high O₂</td>
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<td>4-4-4-8</td>
<td>5-5-6-0</td>
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<td>Engine–generator efficiency, %</td>
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<td>9-21</td>
<td>17-21-4</td>
<td>7-6-23-5</td>
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<td>Al(OH)₃</td>
<td>None</td>
<td>Tar on valves</td>
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<td>Engine exhaust gas composition</td>
<td>Normal</td>
<td>Normal</td>
<td>High O₂</td>
<td>High O₂</td>
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<td>Engine lubrication oil analysis</td>
<td>Poor bearings</td>
<td>Poor bearings</td>
<td>High cooler wear</td>
<td>High engine wear</td>
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<tr>
<td>Overall system efficiency, %</td>
<td>N/A</td>
<td>6-14</td>
<td>12-16-8</td>
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<td>Condensate analysis</td>
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<td>Badly polluted</td>
<td>Hazardous, little</td>
<td>Hazardous, lots</td>
</tr>
<tr>
<td>Carbon monoxide emissions</td>
<td>No danger</td>
<td>No danger</td>
<td>No danger</td>
<td>No danger</td>
</tr>
<tr>
<td>Conclusions</td>
<td>Poor unit</td>
<td>Good unit</td>
<td>Good unit</td>
<td>Good unit</td>
</tr>
</tbody>
</table>

⁸NA = not available.
(2) The engines in Burundi and the Seychelles both had poor bearings probably as a result of producer gas operation. (There is no evidence for this. Most engines in Developing Countries do not receive the manufacturer's suggested level of maintenance and so are in a poorer state than equivalent units in Developed Countries.)

In addition, the problems associated with operating the installations cannot be determined from such a table. However, taken with knowledge of gasifiers and their normal behaviour, such a table highlights the abnormal readings and indicates what sort of behaviour can be expected of gasifiers in the field. Typical values would seem to be (allowing for the Burundi gasifier being a poor unit and rather different from the Mali gasifier):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier conversion efficiency</td>
<td>55–75%</td>
</tr>
<tr>
<td>Gasifier outlet temperature</td>
<td>250–400°C</td>
</tr>
<tr>
<td>Pressure drop (gasifier)</td>
<td>Below 30 cm water</td>
</tr>
<tr>
<td>Gas conditioning system</td>
<td>Below 50 cm water pressure drop; final gas temperature below 70°C</td>
</tr>
<tr>
<td>Gas composition</td>
<td>High oxygen levels are not unusual</td>
</tr>
<tr>
<td>Gas calorific value</td>
<td>4–6 MJ Nm(^{-3})</td>
</tr>
<tr>
<td>Engine/generator efficiency</td>
<td>Up to 23.5%</td>
</tr>
<tr>
<td>Overall efficiency</td>
<td>Up to 16%</td>
</tr>
<tr>
<td>Condensate</td>
<td>Harmful, quantity variable</td>
</tr>
<tr>
<td>Carbon monoxide emissions</td>
<td>Too low to be hazardous</td>
</tr>
</tbody>
</table>

**GENERAL CONCLUSIONS**

Some rather more general conclusions can also be made on the basis of the facts and data presented.

The four reports have tended to highlight the same areas of shortcomings in plants designed over many years, and many thousands of miles apart. The installations do not seem to have been thoroughly tried and tested before being put on the market. How else could such simple matters as nuts and valves being too hot to turn escape notice? In addition, some suppliers overestimate the capabilities of their units, leading to false expectations amongst the clients. The success of the Mali unit demonstrates that, over time, problems can be dealt with to produce a satisfactory installation. The close matching of feedstock and gasifier design is also necessary for a successful gasification plant. Where this is not the case and where specified fuel characteristics are ignored,
problems such as those encountered with installations like the Burundi gasifier will occur. Health and safety matters are not given the same consideration as they would have were the units destined for Developed Countries. The repeated needs for safe disposal methods for the toxic (carcinogenic) waste water streams reflect badly, not only on the suppliers, but also on the clients.

In spite of these problems, it is important to note that, in the examples studied here, the technical capabilities of the installations are not really called into question. The problems that are faced no longer lie in the technology, they have moved into the implementation.

REFERENCES


