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DEMONSTRATION PROGRAMME ON USE OF
INDIGENOUS BIOMASS RESOURCES FOR MEETING ENERGY NEEDS
IN PTA SUBREGION IN AFRICA

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ZIMBABWE

Technical report: Testing programme for two biomass gasifier power plants at Nijo estate, Zimbabwe

Prepared for the Governments of the PTA-countries
by the United Nations Industrial Development Organization

Based on the work of B Kjellström,
Gasification Technology Expert

United Nations Industrial Development Organization
Vienna

EXPLANATORY NOTES

List of acronyms

ADA	Agricultural Development Authority
BOD	Biological Oxygen Demand
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
DOE	Department of Energy
kW	kilowatt
kWh	kilowatthour
Nm^3	Normal cubic meter
O_2	Oxygen
PTA	Preferential Trade Area for Eastern and Southern African States
TOC	Total Organic Carbon
ZESA	Zimbabwe Electric Supply Authority

Petroleum fuel prices

March 1991	Diesel	0.67 ZID/litre
	Petrol	2.54 -"-

Currency exchange rate

March 1991 1 USD = 2.78 ZID

ABSTRACT

On basis of information collected and observations made during a visit to the Nijo estate outside Harare, Zimbabwe, in March 1991, a testing programme for the two generator sets operated with biomass gasifiers at this site, is proposed.

Preliminary tests made during the visit with the generator set delivered by SES, Italy, show that macadamia nut shells and ground nut shell pellets are not suitable feedstocks for this gas producer, since the pressure loss increases to over 1400 mmWG after about 3 hours of operation. Preliminary tests with corn cobs showed no fuel related problems. At the highest load that could be tested, about 20 kW, the specific fuel consumption was found to be 1.4 dry kg/kWh. Attempts to measure the dust and tar contents in the gas showed these contents to be below detection level. Analysis made of the lubrication oil confirms the low dust content in the gas.

Inspection of the dual fuel generator set delivered by ANKUR, India, revealed serious dust contamination of the inlet manifold and the inlet valves after 165 hours of operation with corn cobs as fuel. Measurements of the dust content in the gas showed levels of about 200 mg/Nm^3. Oil analysis confirmed heavy contamination of the engine. Some tests with amended gas filtering arrangements were carried out, but the time was not sufficient for completion of this undertaking. Preliminary tests with this generator set indicates an abnormally high diesel consumption for straight diesel operation. For dual fuel operation the diesel substitution was found to be about 50% and the biomass fuel consumption only slightly smaller than for the SES full gas generator set. It is recommended that the filtering system and the speed control arrangement of the ANKUR generator set are improved before extensive tests with this generator set are carried out.

Observations made during the mission indicate a need for finding a method for more efficient cutting of corn cobs to suitable size and a need for closer monitoring of occupational health.

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I. INTRODUCTION

A. Project background

The programme for the implementation of the Industrial Development Decade for Africa, (IDDA) has put emphasis on the intensification of research and development activities related to developing new and renewable sources of energy at the national, subregional and regional levels. Biomass as a source of energy has been identified as particularly important. At a meeting in December 1987, the Council of Ministers (PTA) encouraged member states to make requests to the international community for assistance regarding biomass energy pilot demonstration projects.

The present project was initiated already in 1985, when UNIDO under the programme for the Industrial Development of Africa, funded a pre-feasibility study to examine the technical and socio-economic viability of generating electricity for rural use by means of gasification of agricultural residue and using the gas as fuel for internal combustion engines. The study /1/, which was reported in 1986, identified corn-cobs, coffee husks/parchment and groundnut shells as the most interesting feedstocks for gasification and recommended a pilot programme focussed on 50 kW modules.

After a study of available gas producer designs for the preferred feedstocks, see /2/ and a study tour to potential suppliers of equipment for the pilot installations, two designs were selected for testing i.e the S E S design from Italy[1] and the ANKUR design from India[2]. The units were purchased in 1989 and installed at the Nijo Estate 30 km outside of Harare in 1990.

A third phase of the project focussed on testing of the units and training of operators was initiated in May 1990. The present report has been prepared as a part of the UNIDO-contribution to this phase, under the job description presented in annex 1. The report was prepared on basis of information supplied by the Chief Technical Advisor, Mr Leif Palm and information collected during a site visit from March 11 to March 28, 1991.

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1 SES (Soft Energy Systems) SpA, Via Marino Ghetaldi 64, I-00143 Roma, Italy

2 ANKUR Scientific Energy Technologies Pvt Ltd, P O Box 2021, Baroda 390 002, India.

B. Objectives of the test programme

The objectives of the testing programme, as specified in the project document for phase III, are:

a. to identify operational and/or design modifications required for operation with different feedstocks available in the subregion;

b. to determine long-term operating characteristics under the prevailing conditions.

C. Difficulties encountered during the site visit

It had been planned that in addition to trying out test procedures for further testing, also some baseline performance data should be collected during the mission in March 1991. Due to unforeseen circumstances this could not be completely achieved.

Upon arrival to Zimbabwe it was found that the SES system was not operational due to modifications of the top part of the gas producer. When making preparations for tests with the ANKUR system it was found that the inlet manifold and some of the inlet valves were clogged with dust. This made it necessary to dismantle the engine top for cleaning which required about two days and manufacture a more effective dust filter before the tests could be started. The actual testing could therefore not start until March 19.

Lack of electric load at the time of the mission was a constraint on the baseline testing that could be made. The extent of the baseline testing was also limited due to unavailability of one of the preferred feedstocks, i.e coffee husks/parchment and due to unexpected difficulties to make arrangements for gas analysis equipment.

It was nevertheless possible to try the proposed test procedures and collect some baseline performance data together with the chief operator. The most essential tasks defined for the mission were therefore completed.

II. SYSTEM DESCRIPTIONS

A. Site description

The two gasifier generator sets were installed at The Nijo estate, operated by ADA and located about 25 km outside of Harare. The estate is connected to the ZESA electric grid and the electricity generated by the two generator sets was therefore not actually needed. During test runs, parts of the local distribution system at the estate could be disconnected from the ZESA grid and hooked up to either of the generator sets.

The two loads avaiable for testing were:

a) An irrigation water pump with a rated demand of about 40 kW

b) An automechanic workshop together with six fans and stokers for coal fired crop dryers. The maximum load was estimated to about 35 kW, including the stokers.

During the testing period in March 1991, the pump could not be used as a load because of electrical problems. Attempts to have these problems sorted out failed because no certified electrician could be made available.

All the tests were therefore done with the fan and workshop load.

A sketch of the site layout is shown as Figure 1.

B. The SES-system

Process scheme

A process scheme for the installation is shown as Figure 2. The individual components are described below.

Gas producer

The gas producer is of the down-draft type with a condensation jacket in the top part. The throat is of the V-type with a throat diameter of 125 mm. Air is sucked through a check valve and supplied through 5 air nozzles, positioned about 100 mm above the throat. There is no grate and the charcoal bed is resting on the floor of the gas producer. The height of the reduction zone is about 200 mm.

During start-up, air is supplied by a pressure fan, which is temporarily connected to the air inlet. The gas leaves the gas producer through two outlets, diametrically positioned.

The gas producer is equipped with ports for ash removal and for supply of additional charcoal to the reduction zone.

Stirring of the fuel bed can be done without opening the top lid by means of a stirrer maneouvered with a crank handle positioned at the top of the gas producer.

The refilling lid at the top, originally had the same diameter as the gas producer i.e about 650 mm. This exposed the operators to large amounts of fumes during refilling. The gasket was also leaking. A modification of the top section was therefore made which resulted in a lid diameter of about 400 mm.

Gas treatment

After the gas producer, the gas passes through two parallel cyclones with a metal chips trap on the inside, a cooler scrubber equipped with a fan for cooling air and a pump for water recirculation, a disk type baffle filter with two parallel passes, each consisting of three filter units and finally through a large bed filter where wood wool is used as filtering material.

Engine

The engine is a six cylinder four stroke FIAT-IVECO diesel engine type 8361i converted to spark ignition operation with producer gas. The maximum power rating for diesel operation was 71 kW at 1500 rpm.

Leading data for the converted engine are:

Cylinder displacement	8.102 dm3
Compression ratio	11:1

Speed control is obtained with a mechanical governor acting on the air throttle, the gas throttle and the mixture throttle.

Generator

The generator is a brushless 3 phase AC generator from Tessari with the following data:

Max rated output	78 kVA
Cos phi	0,8
Frequency	50 Hz
Speed	1500 ppm

Control panel

The generator set control panel is equipped as follows:

- Stop button and start key
- Oil pressure indicator
- Water temperature indicator
- 3 ampere meters
- Volt meter
- Kilowatt meter
- Frequency meter
- Hour meter
- kWh meter[3]
- Controls and alarms
  - unit on
  - battery charger
  - overspeed[4]
  - low oil pressure[4]
  - high water temperature[4]

System instrumentation

The system is equipped with the following instrumentation for monitoring of process conditions:

Gas outlet from gasproducer
- Temperature
- Tap for pressure gauge or gas sampling

Cooler/Scrubber
- Water temperature
- Pressure taps at inlet and outlet

Bed filter
- Pressure taps at inlet and outlet

Carburettor inlet
- Tap for pressure gauge or temperature probe

Operators manual

A 33 pages operators manual with service and maintenance instructions and a trouble shooting scheme has been supplied by the vendor /4/.

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3 Added before the tests in March 1991. Not included in original delivery.

4 Immediate automatic stop of the engine.

Systems specifications

The following specifications of inputs and outputs were supplied by the vendor:

Primary biomass fuel	Wood
Recommended moisture content	15-25%
Recommended fuel size	5x5x5 cm
Rated capacities:	
Gas producer	98.0C0 kcal/h
	120 Nm^3/h
Generator set	35 kW
Performance at rated load:	
Gas producer efficiency	75-80%
Specific fuel consumption	1.3 kg/kWh
Internal electricity consumption	2.2 kW
Pressure loss, gas treatment system	60 cm Wg

Other possible fuels:
Corn cobs, corn cobs/wood mixed with other agricultural residue with low ash content. (Size and moisture content as specified above).

C. The ANKUR system

Process scheme

A process sheme for the installation is shown as figure 3. The individual components are described below.

Gas producer

The gas producer is of the downdraft type. The throat is an integral part of the fuel hopper and has a diameter of 120 mm. Air is sucked through inclined pipes which also constitute the air nozzles. The lenght of the reduction zone from the throat to the fixed grate is about 240 mm. Below the grate, the gas producer extends into an ash chamber which is open at the bottom with the opening submerged in a water pool.

Fuel is fed through a hinged lid at the top of the gas producer.

During start-up, air is sucked through the air inlets by a gas blower positioned after the filtering system.

A vibrator is connected to the gas producer to minimize fuel flow problems.

Gas treatment

After the gas producer, the gas passes a cyclone, a venturi scrubber and a cyclone/fabric filter. The latter filter is equipped with drainage pipes submerged in a water pool. Scrubbing water is recirculated from the pool after a two step sedimentation by means of a pump.

Engine

The engine is a six cylinder, four stroke Leyland-Ashok diesel engine, type ALU 370.

Leading data for the engine are:

Cylinder displacement	6.075 dm3
Stroke	129.65 mm
Bore	103.28 mm
Compression ratio	16:1

The engine is equipped with a mechanical speed governor controlling the diesel injection.

For dual fuel operation the air throttle is closed by the operator until smoke is visible in the exhaust.

Generator

The generator is a brushless 3 phase AC-generator from Kirloskar Electric Co Ltd in India.

Leading data for the generator are:

Rated output	50 kVa
Cos phi	0,8
Voltage	415 V
Frequency	50 Hz
Speed	1500 rpm

Control Panel

The generator set control panel is equipped as follows:

- Main on/off switch
- On/off indicating lamps
- AC Voltmeter with selector switch
- AC Amperemeter with selector switch
- Frequency meter
- kWh meter

System instrumentation

Gas producer outlet
- pressure tap

Cyclone outlet
- pressure tap

Cyclone/fabric filter
- pressure taps at inlet and outlet
- thermometer

Engine
- pressure tap before inlet manifold

Fuel tank
- level gauge
- 500 ml vessel for fuel consumption measurements

Operators Manual

A 13 page Operators Manual /5/ has been provided by the vendor. It includes service and maintenance instructions for commissioning, start-up, continous operation, shut-down as well as service and maintenance. A separate section on trouble shooting is provided and also a section on safety precautions. These do mention carbon monoxide as a highly poisonous gas, but specific instructions on how to avoid poisoning are not included.

Systems specifications

The following specifications of inputs and outputs were supplied by the manufacturer:

Primary biomass fuel	Wood /woody waste
Acceptable moisture content	5-20%
Maximum fuel size	125 mm
Rated capacity:	
Gas producer	100.000 kcal/h 100 m3/h
Generator set	40 kW
Turndown ratio	1:3
Performance at rated load:	
Gas producer efficiency	70-75%
Biomass fuel consumption	1 - 1.2 kg/kWh
Internal electricity consumption	1.9 kW
Typical diesel replacement	65-75%
Gas composition	
CO	19+- 3%
H2	18+-2%
CO2	10+-3%
CH4	up to 3%
Tar	0,005%
Soot	0,005%

D. Special equipment for measurements and monitoring

Fuel moisture content

For determination of the fuel moisture content, a sampling basket (volume 0.015 m^3), a scale and an electric oven with temperature control is available. The scale permits weighing of up to 99 kg with reading of 1 g.

Determination of dust and tar contents

Dust and tar content in the gas should be measured after gas cleaning, just before the gas enters into the engine. The equipment available for these measurements is shown in Figure 4 and consists of:

- A sampling section consisting of a straight tube, diam. 150 mm and length 1500 mm with a 90° bend where a sampling probe can be introduced.

- A probe for isokinetic sampling

- An electrically heated filter vessel

- A gas cooler with gravity water cooling connected to a beaker for condensate collection.

- A fibre glass bed filter

- A gas meter

- Valves for flow control

- A sampling pump

- An inclined U-tube manometer connected to the sampling probe

- A U-tube manometer for measurement of the pressure before the gas meter

Dust is collected in filter cartridges which are positioned in the heated filter. In March 1991 only cellose cartridges were available but these should be substituted with micro glass cartridges in future tests, see footnote 9 on page 24. Tar is collected in the gas cooler and the condensate beaker. The determination of the dust and tar is based on determination of the weight change of the filter cartridge (weight of dust) and the weight change of the cooler/beaker (weight of condensates) when a certain volume of gas (measured with the gas meter) is passed trough the system.

The filter cartridges and the cooler/beaker must be dried and weighed before the tests. The filter cartridges must be re-dried after the tests before weighing. In March 1991 the oven at the project was used for drying at 104 °C. The filter cartridges were then, when still warm, packed in three layers of polyethylene bags and brought to the University where a scale of adequate accuracy was available. During weighing, which for logistic reasons often had to be done about 15 hours after drying and packing, the cartridges gained weight rapidly by moisture pick-up. It was therefore necessary to note the weight within seconds after placing the cartridge on the scale. The risk for moisture pick-up during handling and transport is obvious and it is therefore recommended that, for future tests, the oven is brought to the University to minimize time between drying and weighing.

E. Operating personnel

In March 1991, the following staff was available at the project site for operation of the two generator sets:

1 Chief operator
3 Operators
3 Casual laborers

Only the Chief Operator had received training by representatives of the vendors during the comissioning period. The training time was estimated to about seven days, or little more than three days on each unit. No written instructions had been provided at that time[5]. The other operators had been trained on the job by the Chief Operator and the Chief Technical Advisor.

F. Operating history

Since installation on the site, the SES unit had been operated for 299 hours and the ANKUR unit for 164 hours before the tests reported in Chapter IV were started.

Both units had shown some problems in operation. Internal explosions had occurred on several occassions in the SES-system. Damage to the top lid and the gasket as a result of such explosions had occurred twice. In order to avoid this problem, the top part of the gas producer was modified before the tests reported in Chapter IV. Problems with cracking of the plastic hoses connecting the gas producer and the cyclones had also been experienced. The substantial carry-over of dust to the engine appeared as the main problem with the ANKUR-system. Inspection of the inlet manifold after 164 hours of operation showed severe deposits in the inlet manifold and the inlet valves. Detorioration of the filter cloth as a result of frequent washing[6] might have contributed to this problem.

Hunting or difficulties to maintain load had been experienced

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5 The operators manuals had been received later.

6 Washing is necessary to avoid high pressure losses. It appears that washing has been done at intervals of less than 20 hours.

with both systems. In case of the SES system, excessive play in the control mechanism, caused by wear appears to be the main reason.

III. RESULTS OF PRELIMINARY TESTS

A. Objectives of the tests

The main objectives of the tests made in March 1991 were:

a. to check testing procedures and the adequacy of the measurement equipment available at the project;

b. to make scoping tests, the results of which should be used for planning of further testing.

The results of the tests may also partly be used as a baseline for the further testing.

Due to unforeseen circumstances discussed in section 1.C, the extent of the testing that could be carried out during the limited time available was less than originally planned. The main objectives of the preliminary tests were achieved however.

B. Fuels tested

Both gas producers are specified for wood as primary fuel. Rated performance data refers to this fuel.

The project however is focussed on utilization of agricultural residue, in particular coffee husks, ground nut shells, shells and corn cobs. At the time of the mission only corn cobs, ground nut shell pellets, macadamia nut shells, cotton stalks and wood were available in sufficient quantities at the project site.

Because of the time constraints discussed in the introduction it was decided by the project director to focus the tests on maize cobs, ground nut shells (pelletized), macadamia nut shells and wood. The wood tests could not be done during the mission.

Table 1 gives an overwiev of fuel properties and figure 5 shows photos of fuel samples.

Table 1. Summary of fuel properties

Fuel	Fuel preparation	Moisture content %	Particle size	Bulk density dry kg/m3
Wood	Air dried and cut into blocks[1]	2)	about 1x2x6 cm	2)
Corn cobs	Air dried and cut into three pieces[1]	11 -14	diam 3 cm lenght 4-6 cm	130
Macadamia nut shells	As received	8	1-2 cm	400
Ground nut shells	Pelletized	9	diam 23 mm lenght 2-5 cm	450

1) Done manually on site
2) To be determined by the Chief Operator

C. General observations

Fuel preparation

The main feedstock used at the project is corn cobs. The length of the cobs as received is about 20 cm, which is too much for trouble free operation of the gas producers[7]. The cobs are manually broken into three pieces of about 6 cm length. Three casual labourers are occupied with the fuel preparation at a cost of 6.85 ZID/day. The daily production of one labourer was found to be 15 bags or about 135 kg of broken cobs. This implies a fuel preparation cost of about 51 ZID/ton, which is equivalent to 18 USD/ton. Such a high fuel preparation cost will no doubt reduce the financial attractiveness of biomass gasification compared to diesel operation. It is therefore essential that efforts are made to find cheaper fuel preparation methods.

7 Full size cobs were not tried in March 1991. Earlier tests with full size cobs run by the Chief Operator were however reported to be troubled with bridging in the fuel bed.

Occupational safety

Poisoning by carbonmonoxide, skin burns from hot surfaces or flames penetrating through openings in the gas producer and injuries from objects missiling after internal explosions are the main occupational hazards associated with operation of gas producers.

The experiences from the operation in March 1991, after modification to the upper part of the SES gas producer, indicates that the internal explosion risk has been reduced.

The arrangement with "buck-sails" shielding the installations from wind will certainly increase the exposure to fumes from the gas producer during re-fuelling, with a potential risk for carbon monoxide poisoning. With the arrangements on site, where the re-fuelling lids open directly into the gas producer, the risk for poisoning depends primarily on the behaviour of the operator.

Measurements in March 1991 for both systems with the engine running, using Kitigawa detector tubes, showed CO-concentrations in the range 50 - 300 ppm around open re-fuelling lids. This is not alarming and would allow the operator to spend at least 30 minutes working in this atmosphere without mild symptoms of poisoning. This method for measurements is however not very suitable for determination of peak concentrations and it is quite possible that larger concentrations occur. A portable instrument for continuous detection or individual "dose-meters" would be more adequate.

The need for attention to the poisoning problem is emphasized by remarks made by the Chief Operator about feeling weak and loosing appetite during his initial period at the project and by the outbreak of mental disturbance for one of the operators during the March 1991 mission.

Environmental impacts

Both systems generate a liquid residue which could be a potential pollutant. Samples of the liquid residues were collected during the mission in March 1991. They were left for analysis of BOD, COD and phenols content but the results of the analysis have not been received when this report is written.

If the analysis shows that the residue is a potential pollutant, procedures for simple treatment of the residue on site should be developed. Preliminary tests with incineration of condensates from the SES-system, using the fine charcoal residue as fuel had already been done at the project.

D. Tests with the SES-system

Condition of the equipment

Before the tests in March 1991, the SES generator set had been operated for 299 hours using broken corn cobs as fuel. Since no kWh meter had been installed for this generator set, the average output power for previous operation can not be calculated.

The general condition of the equipment appeared as good, with exception of the mechanical governor linkage which had worn bearings leading to excessive play. There were also some minor problems like clogging by tar of the check-valve at the air inlet and indications of outside corrosion of the lower two pairs of baffle filter vessels caused by condensate dripping from the drain valves of vessels positioned above. The log book of the Chief Operator also indicated that problems had been experienced with cracking of the hoses between the gas producer and the filtering system.

After several internal explosions, the top part of the gas producer was modified in March 1991 giving a reduced diameter of the refuelling lid from about 650 mm to 430 mm.

A kWh meter was installed on March 19 after 299.1 recorded engine operating hours.

Overview of tests done in March 1991

The SES generator set was tested with corn cobs, macadamia nut shells and ground nut shell pellets. Tests with wood as feedstock started on the last day of the mission and were completed by the Chief Operator.

Table 2 gives an overview of the test results. The tests are commented in more detail below.

Tests with corn cobs

Corn cobs were tested during four days and covered 21 hours of operation. Speed control problems caused by the worn linkage system for the speed control throttles required more or less continuous supervision and interventions from the operator at irregular intervals. Besides these, feeding the gas producer at intervals of about 30 minutes was the only action required from the operator.

The test results indicate a more or less constant biomass fuel consumption per hour. This results in increasing specific fuel

Table 2. Preliminary tests with the SES-system

Fuel	Corn cobs			Macadamia nut shells	Groundnut shell pellets
Moisture content %	11.7	16.1	15.0	9.0	10.0
Date	19/3	20/3	22/3 - 23/3	25/3	26/3
Duration of test, hours	3.5	7.0	10.5	3.3	3.2
Average load, kW	6.5	19.6	13.1	14.2	19.2
Specific fuel consumption					
kg/kWh	4.1	1.4	1.9	2.3	1.9
kg/h	30.2	28.2	24.6	32.7	37.1
Pressure losses:					
Gas producer					
initial, mmWg	170	95	-	390	305
end of test, mmWg	75	150	-	1590	1420
Filter system mmWg					
initial, mmWG	600	185	-	130	200
end of test, mmWg	120	310	-	150	220
Gas composition:					
CO %	-	-	18.0	19.2	20.8
O_2 %	-	-	1.5	4.6	3.2
CO_2 %	-	-	10.5	8.0	7.8
Dust mg/Nm^3	< 7	< 7	-	-	-
Tar mg/Nm^3	no condensate		-	-	-
Condensates, % of fuel moisture	-	35	75	63	47

consumption with decreasing load, ranging from 4.1 kg/kWh at 6.5 kW average output to 1.4 kg/kWh at the highest output tested i.e 19.6 kW. No tests could be made at rated electric output, 35 kW, due to lack of load. The specific fuel consumption of 1.3 kg/kWh at rated output, claimed by the vendor, could therefore not be verified. Further tests are needed for this.

The pressure losses across the gas producer and the filtering system varied during the tests. The overall pressure loss was generally within the range of 600 mm claimed by the vendor for the filtering system only.

Gas composition measurements were limited to carbon monoxide (CO), oxygen (O_2) and carbon dioxide (CO_2). The results are within the normal range.

Attempts to measure the amounts of dust in the gas after the filtering system did not result in quantitative data because the content was below the detection limit of the method used, i.e less than about 7 mg/Nm^3. No condensates were collected from the gas sampled after the filtering system when cooled by water at 23 °C. This indicates that tar is not present in the gas in concentrations that will cause problems in the engine.

Amounts of liquid residues collected from the system are given in Table 3. Samples of the liquids were sent for analysis of BOD, COD and phenols content, but the results are not yet available.

Inspection of the charcoal bed in the bottom of the gas producer after the 21 hours of operation on corn cobs, showed a gradient in the bed height across the outer annulus which indicates non-uniform flow distribution. The fraction of fines in the charcoal bed in the outer annulus was high. White ash in the bed just inside the lids indicates some air leakage through the lid sealing. The entire charcoal bed was removed and sieved. No large slag lumps were found, only small pieces of a few cm, with a total weight of 30 g. After sieving, the remaining larger pieces charcoal were put back into the gas producer together with 24.4 kg of fresh charcoal required to replace the charcoal consumed during operation and lost as fines during the sieving. It appears that the SES gas producer is not capable of generating enough charcoal for sustainable operation and that the specific charcoal consumption, in addition to the biomass fuel consumption, is about 0.08 kg/kWh.

Tests with Macadamia nut shells

Macadamia nut shells were tested only for one day. The duration of the test was 3.3 hours and the average output 14.2 kW.

Before the tests, the gas producer had been completely emptied and recharged with fresh charcoal according to instructions in the manual supplied by the vendor.

Already from the start of the test, a high pressure loss over the gas producer could be observed. The pressure loss increased continuously and reached over 1500 mmWg after 3 hours of operation. At the end of the test the engine could just barely meet the load of 19.8 kW.

The measurements of the gas composition showed a high oxygen content, which can be explained by air leakage caused by the low pressure in the system. Correcting for the air leakage, the gas had a very high content of carbonmonoxide which indicates that the nut shells as such are an excellent feedstock for gasification. The specific fuel consumption was found to be higher than for corn cobs at a comparable load. The difference can at least partly be explained by the shorter duration of the macadamia nut shell test.

Inspection of the fuel bed in the gas producer after the test revealed large slag lumps (up to 15 cm) in the throat zone. The total weight of slag was 0.33 kg[8]. The amounts of liquid residues collected from the system are given in Table 3.

On basis of the rapid increase of the pressure loss over the gas producer and the slag formation, it must be concluded that macadamia nut shells is not a suitable feedstock for this type of gas producer.

Tests with groundnut shell pellets

Gruond nut shell pellets were tested only for one day. The duration of the test was 3.2 hours and the average output 19.2 kW.

Before the tests, the gas producer had been completely emptied and recharged with fresh charcoal according to instructions in the manual supplied by the vendor.

In general, the experiences from this test were very similar with those from the test with macadamia nut shells. A high pressure loss over the gas producer was observed from the start of the test and this increased continuously to reach over 1400 mmWg after 3 hours of operation. At the end of the test the engine could just barely meet the load of 19.4 kW.

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8 The macadamia nut shells used for the tests were "sweep-ups", heavily contaminated with soil when recieved. The shells were washed with water before used as feedstock for the gas producer, but it is possible that the slag formation is not typical of what would be found with clean shells.

The measurements of the gas composition showed a high oxygen content, which again can be explained by air leakage caused by the low pressure in the system. Correcting for the air leakage, the gas had a very high content of carbonmonoxide which indicates that the pellets as such are an excellent feedstock for gasification. The specific fuel consumption was higher than for corn cobs at a comparable load. Again this can partly be explained by the short duration of the pellets test.

Inspection of the fuel bed in the gas producer after the test revealed large slag lumps (up to 15 cm) in the throat zone. The total weight of slag was 0.42 kg. Amounts of liquid residues collected from the system are given in Table 3.

On basis of the rapid increase of the pressure loss over the gas producer and the slag formation, it must be concluded that groundnut shell pellets is not a suitable feedstock for this type of gas producer.

Residues

In addition to exhaust gases from the engine, which are generated by all generator sets driven by internal combustion engines, the SES gasifier generator set produces four types of residue, namely:

- Ash and charcoal fines collected from the gas producer, the cyclones, and the baffle filter (solid);

- Dirty wood wool from the bed filter (solid);

- Gasifier condensate (liquid);

- Filter system condensate collected from the srubber, the baffle filters and the bed filter (liquid).

Of these, only the liquid residues are expected to give potential disposal problems. The quantities were therefore determined and samples sent for analysis. The results are shown in Table 3. The results of the analysis are not available when this report is prepared.

The quantities generated during a period of operation should be related to the amount of moisture entering into the gas producer i.e primarily with the feedstock. For this reason, the amounts of condensate have been expressed as a fraction of the moisture supplied with the feedstock in Table 3. On basis of the results obtained in March 1991 it appears reasonable to assume that up to about 75% of the moisture in the feedstock may end up as condensate. The fraction appears to vary however and further tests will be needed to arrive at an accurate estimate.

Table 3. Liquid residues produced by the SES-system

Date	20/3	22 - 23/3	25/3	26/3
Feedstock	Corn cobs		Macadamia nut shells	Groundnut shell pellets
Total amount of feedstock supplied, kg	235	297	247[1)]	276[1)]
Feedstock moisture %	16.1	15.0	9.0	10.0
Water supplied with feedstock kg	37.8	44.6	22.2	27.6
Condensates, kg: Gas producer	4.0	11.5	3.0	3.0
Filter system	9.5	22.0	11.0	10.0
Fraction of fuel moisture collected %	35	75	63	47

Note:
1) Including initial filling.

Results of oil analysis

A sample of the lubrication oil in the engine was taken and sent for analysis at ZEMCO. The operating hours on the engine at the time of the sampling was 309.6, and probably 100 hours since the last oil change. The results obtained are presented in table 4.

Table 4. <u>Results of lubrication oil analysis for the SES-system</u>

<u>Wear metal concentrations ppm</u>

Cu	Fe	Cr	Pb	Al	Si	Mo	Na	Mg	Sn
0	440	0		3	0				

<u>Oil condition/contaminants</u>

Water	Fuel	Soot	Oxidation	Sulphur
nil		nil	13%	7%

The comments from the laboratory on the test results were:

Evaluation:
Iron is slightly high. All other elements test results appear as normal.
Recommendation:
No action is required at this time. Oil is suitable for further use. Sample regularly to monitor.

The results from the oil analysis confirms the observations from the measurements of the dust content in the gas, namely that the gas is quite clean.

Needs for further testing

Needs for further testing of the SES-system are discussed in section VI.D.

D. Tests with the ANKUR-system

Condition of the equipment

Before the tests in March 1991, the ANKUR generator set had been operated for 164 hours using broken corn cobs as fuel. The kWh meter showed 990 kWh indicating an average load of about 6 kW.

The inspection of the equipment before the tests revealed several indications of detorioration of the system. The most serious problem found was the significant (locally several mm thick) deposits of dust in the gas pipes after the wet filter, in the inlet manifold and the inlet valves. The poor condition of the filter fabric could explain the large dust carry-over. The pump for the scrubber and the blower used for start-up, both showed a tendency of seizing. The exhaust manifold of the engine was leaking.

Overview of tests done in March 1991

It was decided to clean the engine before the tests since further operation with the engine in its present condition was not considered meaningful. It was also decided to minimize operation with the original filter system since the high dust carry-over shows that its performance is clearly inadequate. Finally it was decided to focus the testing on amended filter systems since provision of such would be necessary before extensive operation of the ANKUR generator set could be started.

The tests included some short runs to determine the diesel consumption for straight diesel operation, two tests with corn cobs as fuel, primarily focussed on determination of the dust content in the gas after filtering for the original and amended filtering system and a very short test with the original filter fabric replaced with a more closely woven fabric.

Straight diesel operation

The diesel consumption was measured only for idling and at a load of 11 kW. The results are summarized in Table 5.

Table 5. Diesel consumption for straight diesel operation of the ANKUR generator set

Load absolute kW	relative to rated of 40 kW	Diesel consumption kg/h	g/kWh
idling	0	4.0	
11	0.275	7.3	580

Time did not allow determination of the diesel consumption at higher loads. It is essential that this is done, since this is an important reference for assessment of the performance in dual fuel operation. It appears however that the diesel consumption is very high. Figure 6 shows typical performance data for naturally aspirated small diesel engines. At about 27% load, a consumption of about 400 g/kWh would be normal.

Tests with corn cobs

Table 6 shows a summary of the results obtained with dual fuel operation of the generator set when corn cobs were used as feedstock for the gas producer. The first test on March 21 was done with the original filter system, the second on March 27 with a new dry fabric filter added after the wet filter. Although the main purpose of the tests was to study the performance of the filtering system, some experiences from use of corn cobs as feedstock in this design of gas producer were also gained.

The experience from the two tests showed that frequent manual adjustment of the throttling valve on the air inlet is necessary with the present control system to maintain the best possible diesel substitution. Both tests showed that the control system is not adequate for achieving a high diesel substitution. The substitution is certainly less than 53% and much less than the 65 - 75% claimed by the vendor. In fact the specific diesel consumption in dual fuel operation is close to what would be expected for a well adjusted engine operating in straight diesel mode, compare Figure 6. Since the specific biomass fuel consumption of 1.0 to 2.2 kg/kWh is not much less than for the full gas SES-system at comparable load, see Table 2, it is reasonable to question if biomass gasification is at all meaningful in a system of this design.

Results of oil analysis

A sample of the lubrication oil in the engine was taken and sent for analysis at ZEMCO. The operating hours on the engine at the time of the sampling was 165. There had been no change of the lubricating oil since the installation on the site. The results of the oil analysis are presented in table 7, together with comments from the laboratory.

The results of the oil analysis confirms other observations made during the tests namely the high dust carry-over and the high diesel consumption.

Table 6. Preliminary tests with the ANKUR-system

Fuel	Corn cobs	
Moisture content %	11.1	12.0
Date	21/3	27/3
Filter system	Original	Modified
Duration of test, hours	3.3	5.7
Average load, kW	9.9	19.4
Specific biomass fuel consumption, kg/kWh	2.2	1.0
kg/h	22.2	19.4
Specific diesel consumption, kg/kWh	0.31	0.27
Diesel substitution %	46	< 53
Pressure losses:		
Gas producer		
initial mmWg	63	65
end of test mmWg	1000	25
Filter system mmWg		
initial mmWg	2	90
end of test mmWg	10	1175
Gas composition:		
CO %	-	11.6
O_2 %	-	4.6
CO_2 %	-	13.2
Dust mg/Nm^3	about 200	83
Tar mg/Nm^3	no condensates collected	

Table 7. Results of lubrication oil analysis for the ANKUR-system

Wear metal concentrations ppm

Cu	Fe	Cr	Pb	Al	Si	Mo	Na	Mg	Sn
68	521	1	35	41	17				

Oil condition/contaminants

Water	Fuel	Soot	Oxidation	Sulphur
nil	3%	50%	7%	37%

The comments from the laboratory on the test results were:

Evaluation:
This sample contains excess fuel dilution. Wear metals and silicon appear above normal. Check for dirt entry.
Recommendation:
Check injectors and or overfuelling. Suggest changing oil and filter(s). Sample regularly to monitor.

Tests with different filtering systems

After the initial inspection of the ANKUR-system it was evident that amendment of the gas filtering would be necessary before extensive testing of the system was started. The testing of the ANKUR-system in March 1991 was therefore focussed primarily on the performance of different arrangements for gas cleaning. The tests included pressure loss measurements and also, for two arrangements, measurements of the dust content in the gas after filtering. The latter measurements were done with the equipment and procedure described in section V.E, however using cellulose filter cartridges rather than the glass fibre cartridges recommended in section V.E[9].

Although the amount of dust deposits in the inlet manifold and the results of the lubrication oil analysis are sufficient

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[9] Only cellulose cartridges were available. Earlier experiences with these cartridges show that a weight loss is sometimes found when the cartridges are exposed to repeated drying. Similar experiences were made here, where three blind samples (not exposed to the gas flow) showed weight losses of 0.001, 0.006 and 0.011 g respectively when re-dried and weighed. The average weight loss (0.006 g) of the blind samples was added to the weight increase found for the cartridges used for dust collection. The correction is equivalent to about 16 mg/Nm^3.

indicators of inadequate gas filtering, it was still decided to measure the dust content in the gas after the original wet filter. This filter used a felt-like material of unknown origin which after 165 operating hours and several washings appeared fairly threadbare. The duration of the test with this filter was 3.3 hours during which the pressure loss over the filter increased from a marginal 2 mmWG to a still insignificant 10 mmWG. Three measurements of the dust content in the gas after filtering were made. The results show a gradual decrease of the dust content from 250 to 192 to 10 mg/Nm^3. A possible explanation for the low dust content measured towards the end of the test is the lower gas flow resulting from the lower system pressure caused by increasing pressure loss over the gas producer. The gas flow can be estimated from the diesel substitution which dropped from a peak value of 62% to 26% towards the end of the test. Figure 7 illustrates how synchronous observations of gas dust content and gas energy rate varied during the test.

After this test, a test was then done with the original filter fabric substituted by a locally purchased cotton cloth (quilt). The pressure loss over the filter was found to increase very rapidly and it was concluded that a much larger filter area would be needed with this filter fabric. No measurements of the dust content in the gas after the filter were made.

Finally a test was carried out with an added dry fabric filter, positioned after the original wet filter. This filter was equipped with the same local cotton cloth, but had a much larger filter area. The duration of this test was 5.7 hours, during which the pressure loss across the dry filter increased from an acceptable 90 mmWG to an unacceptable 950 mmWg. The dust content in the gas after filtering was found to be 83 mg/Nm^3 at an estimated gas energy rate of 71 kW. This dust content is lower than for the original filter system but still high in comparison with recommended values of less than 10 mg/Nm^3. Also the rate of increase of the pressure loss was found too high to be acceptable in practical operation[10]. Inspection of the filter after the test revealed that the wire structure used as support for the filter fabric had not been rigid enough. This had resulted in partial collapse of the filter and a significant reduction of the effective filter area. It is possible that better performance would be found if the test would be repeated with a strengthened fabric support.

Needs for further testing

Needs for further testing of the ANKUR-system are discussed in section VI.E.

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10 It is reasonable to require at least 8 hours of operation between filter cleanings.

IV. PROPOSED TESTING PROGRAM

A. General remarks

Objectives

The objectives of the testing program proposed in the following are:

- to identify types of agricultural residue which can be used as gasification fuel in either of the two designs of gas producers;
- to verify acceptable performance in prolonged operation before bringing the installations to the field;
- to collect performance data which can be used for a financial and economic evaluation of biomass gasifier installations for small scale power generation;
- to collect data and experiences which can be utilized for design of a system, adapted to the requirements of Zimbabwe, which can be manufactured locally.

Types of tests

The tests are of four types as summarized below:

- Scoping fuel tests, with a duration of about 6 hours, focussed on identification of problems like bridging, serious slagging, extensive tar production and rapidly increasing pressure losses which makes a fuel clearly unsuitable for commercial operation.
- Baseline tests, with a duration of 18 - 22 hours, focussed on determination of performance data under controlled conditions.
- Extended operation tests, with a duration of about 400 hours, focussed primarily on collection of data on engine contamination and system detorioration.
- Scoping system modification tests, focussed on determination of the change in a specific performance parameter as a result of a system modification.

Overview of the testing programme

Since the initial operating experiences and the initial tests show that the technical status of the two installations are quite different, the testing programs have been accordingly adapted.

The SES-installation appears, so far, as technically acceptable for field operation. The focus of the testing will therefore be on scoping fuel tests, baseline tests, prolonged operation tests and scoping system modification tests. The latter tests will focus on possibilities for simplification of the gas treatment, by elimination of one or several treatment steps.

The ANKUR-installation has been found to suffer from major performance deficiences. Until system modifications have been made which eliminate these deficiences, testing beyond what is required for checking of system modifications is hardly justified. After introduction of system modifications the tests will include scoping fuel tests, fuel consumption tests and prolonged operation tests.

When the programme is completed, the following fuels should have been subject at least to scoping fuel tests in both systems:

- Wood
  as dry wood blocks, carpentry residue

- Maize cobs
  as whole cobs and broken cobs

- Coffee husk
  as recieved

- Groundnut shell
  as pellets

- Macadamia nut shells
  as recieved

- Cotton stalk
  as cut into pieces 5 - 10 cm length

B. Fuel preparation tests

The need for finding a cheaper method for preparation of corn cobs for gasification was pointed out in section III.C. The somewhat disappointing experiences with the manually cranked shredder indicate that a device operating on the principle of feeding the cobs in line through one or several tubes to a rotating knife might be more succesful.

C. Monitoring of occupational health

The need for close monitoring of indications of carbon monoxide poisoning was also pointed out in section III.C. All project personell should be given medical check-ups. Measurements of individual exposures using passive diffusion reaction tubes[11], which give the accumulated dose in ppmh, and possibly measurements of local peak concentrations of carbon monoxide with an instrument giving a direct reading, are also recommended.

D. Testing programme for the SES-system

The tests made up to March 1991 indicate that the function of the SES-system with corn cobs as feedstock is in general acceptable. Maintenance of the linkage system for the speed control, in order to eliminate excessive play is however recommended - at least before extended tests are started.

The further testing should include:

- Scoping tests with wood, coffee husk/parchment, and cotton stalks. Recommended procedures are outlined in section V.C.

- Baseline tests with corn cobs and those feedstocks which have shown acceptable performance during the scoping tests. Recommended procedures are outlined in section V.D.

- Extended test with corn cobs. The recommended procedure is outlined in section V.E.

After the extended tests it could be useful to run special tests for studying the effect of removing one or two cleaning steps on the dust content in the gas. The results of such tests would indicate if a simpler and cheaper system could be built without too much sacrifice in performance.

E. Testing programme for the ANKUR-system

As a reference for the tests with dual fuel operation, it is essential that diesel consumption data for straight diesel

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11 For instance Draeger 6733191.

operation at five different loads[12] from idling to rated load (40 kW) are established. The recommended procedure is outlined in section V.A. If the tests confirm the findings from the limited testing in March 1991, i.e that the diesel consumption is abnormally high[13], adjustments should be made and the tests repeated.

Tests with dual fuel operation of the ANKUR-system can not be recommended until the filter system has been adequately improved to give a dust content in the gas after filtering of at least below 50 and preferrably below 10 mg/Nm^3. Extensive tests with the present filter system will inevitably result in rapid engine wear. Tests with improved filter systems could include:

- improving the dry fabric filter tested on March 1991;

- utilization of parts of the cleaning system of the SES-system;

- including other types of bed filters, for instance the Fluidyne design[14].

It can also be questioned if dual fuel tests with the present control system is meaningful. The diesel substitution is much less than can be achieved with well functioning arrangements and the biomass fuel consumption almost the same as for the full gas SES-generator set. An arrangement similar to that used by the National Institute for Machinery Testing in Sweden[15] or by Fluidyne Gasification Ltd is recommended. These control systems should give a substitution of at least 80% with a well functioning gas producer. An alternative could be to actually convert the engine of the ANKUR-generator set to full gas operation. Experiences from conversion of Volvo-engines in Sweden indicates however that this option is more expensive.

When the two present weaknesses of the ANKUR-system, discussed above, have been eliminated, further testing should include:

- Scoping tests with wood, ground nut shell pellets, coffee husk/parchment, cotton stalks and macadamia nut shells. Recommended procedures are outlined in section V.C.

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12 Roughly the following loads shold be chosen for testing: idling, 25%, 50%, 75% and 100%

13 Specific consumption data in Figure xx can be used as a benchmark.

14 Fluidyne Gasification Ltd, P O Box 21583, Hendersson, Auckland 8, New Zealand.

15 Statens Maskinprovningar, Box 1002, S-901 11 Umeå, Sweden.

- Baseline tests with corn cobs and those feedstocks which have shown acceptable performance during the scoping tests. Recommended procedures are outlined in section V.D.

- Extended test with corn cobs. The recommended procedure is outlined in section V.E.

V. TESTING PROCEDURES

A. Diesel consumption measurements

Diesel consumption measurements should be carried out for full diesel operation of the ANKUR generator set as recommended in section IV.E but also during scoping and baseline tests, see V.C and V.D.

The following procedure is recommended:

1. Start the engine, run it idling for a few minutes and put on the desired load. Let it run on this load for at least 10 minutes.

2. Fill the measuring glass with diesel.

3. Switch to diesel flow from the measuring glass and recirculation back to the measuring glass.

4. When the liquid surface in the glass passes the 500 ml level, start a stop-watch <u>and</u> start counting turns on the kWh meter.

5. Stop the watch and stop counting when the liquid surface passes the 100 ml level.

6. Shift to diesel flow from tank but keep recirculation into measuring glass, thereby refilling the glass above the 500 mml level.

7. Shift to diesel flow from the measuring glass.

8. Repeat from 4.

9. After 3 repetitions switch over to diesel flow from main tank and recirculation back into tank.

10. Change load and let it run on new load for at least 5 minutes.

11. Repeat from 2.

12. Calculate the power output P for each test as:

$$P=\frac{3600 \times Numberofturns}{15 \times Time} kW$$

where time is the time for consumption of 400 ml expressed in seconds.

13. Calculate the specific fuel consumption b_s for each test as:

$$b_s=\frac{0.87 \times 400}{\frac{Numberofturns}{15}} g/kWh$$

14. For each load tested, calculate average values for power output and specific fuel consumption.

B. Biomass fuel moisture content

The following procedure is recommended:

1. Samples from the entire fuel batch shall be collected in the net basket. In general this will mean that "a handful or two" of fuel is taken from each fuel bag (at an intermediate level in the bag).

2. Weigh the basket with fuel as soon as sampling has been completed.

3. Dry the fuel in the oven at 104 °C and weigh at intervals of a few hours until no further change in weight is recorded[16].

4. Calculate moisture content (wet basis) as:

$$M.C = \frac{\text{Initial weight - Final weight}}{\text{Initial weight - Basket weight}}$$

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16 Please observe that the drying time will depend on the initial moisture content as well as the size, shape and structure of the fuel particles.

C. Scoping fuel test

The following procedure is recommended:

1. Empty the gas producer, drain condensates, clean the filters, prime the gas producer with charcoal according to instructions in manual and fill the fuel to be tested up to about half level.

2. Ignite fuel bed in gas producer and start engine.

3. After about 15 minutes, put on about 80 % load. Operate on this load for 1 hour, re-fuelling the gas producer if necessary.

4. Fill the gas producer to a given level[17], stir fuel bed and refill to level if necessary. Note time and position of kWh meter[18]. Start tar and dust sampling according to instructions under E[19].

5. Weigh each bag of fuel supplied from this time on. Also, take fuel sample from each bag for moisture analysis, see instructions under B.

6. Maintain load for 6 to 8 hours. Take readings of kWh-meter each 30 minutes to document load variations. Also, take readings of pressures and temperatures at standard positions and make notes on needs for operator interventions, for instance for stirring of fuel bed.

   For the ANKUR-system, make diesel consumption test according to instructions under A. at least each hour.

7. After completion of the test run, note time and position of kWh meter, fill the gas producer to the same level[16], stir fuel bed and refill to level if necessary.

8. Calculate specific fuel consumption as total weight of fuel supplied from step 4 to step 7, divided by total kWh generated during same period.

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17 Top of cylindrical part in SES gas producer, at top lid in ANKUR gas producer.

18 For ANKUR system, the number of turns on the kWh-meter must be counted from this time on, since the accuracy of the meter is not adequate for these tests.

19 Only necessary if other factors like high pressure loss, serious bridging and excessive slag formation are not expected to be limiting.

9. After the gas producer has cooled down, ventilate system, remove fuel bed and inspect for crumbling of charcoal, large slag lumps, caked fuel and similar. Document observations.

D. Baseline tests

General

It is recommended that complete baseline tests as outlined below, are carried out for fuels of major interest. The complete test covers 5 operating days, where the first and the last day are run at a reasonably high load and include determination of start-up and shut-down losses. Days 2 to 4 are used for fuel consumption measurements at constant loads over the entire load range. Detorioration of performance during the five day operating period can be determined by comparison of the specific fuel consumptions of day 1 and 5 and the two determinations of the specific fuel consumptions at 100 % load on days 2 and 4.

Limited baseline tests may be carried out for less important fuels which have been found acceptable during the scoping tests.

Preparations

The following procedure is recommended:

1. Empty the gas producer, drain condensates, clean the filters, prime the gas producer with charcoal according to instructions in manual.

Specific fuel consumption including startup and shutdown losses

It is suggested that these tests are conducted on Day 1 and 5 of a complete five day baseline test program.

The following procedure is recommended:

1. Fill the gas producer to a given level[16], stir fuel bed and refill to level if necessary. Note time and position of kWh meter[20].

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[20] For ANKUR system, the number of turns on the kWh-meter must be counted from this time on, since the accuracy of the meter is not adequate for these tests.

2. Ignite fuel bed in gas producer and start engine.

3. After about 15 minutes, put on about 80 % load.

4. Weigh each bag of fuel supplied from the start of the test. Take fuel sample from each bag for moisture analysis, see instructions under A.

5. Maintain load for 6 to 8 hours. Take readings of kWh-meter each 30 minutes to document load variations. Also, take readings of pressures and temperatures at standard positions.

   For the ANKUR-system, make diesel consumption test according to instructions under A. at least each hour.

6. After 6 to 8 hours, note time and position of kWh meter, stop engine and close gas producer.

7. Next day, fill the gas producer to the same level[16], stir fuel bed and refill to level if necessary.

8. Calculate specific fuel consumption as total weight of fuel supplied from step 4 to step 7, divided by total kWh generated during same period.

9. Collect and measure volume of condensates drained from different drainage points after each of the two operating days.

Specific fuel consumption at given load

It is suggested that these tests are conducted on Days 2 to 4 of a complete five day baseline test program, see point 10 below.

The following procedure is recommended:

1. Drain condensates.

2. Ignite fuel bed in gas producer and start engine.

3. After about 15 minutes put on the load to be tested. Operate on this load for 1 hour, re-fuelling the gas producer if necessary.

4. Fill the gas producer to a given level[16], stir fuel bed and refill to level if necessary. Note time and position of kWh meter[21].

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[21] For ANKUR system, the number of turns on the kWh-meter must be counted from this time on, since the accuracy of the meter is not adequate for these tests.

5. Weigh each bag of fuel supplied from this time on. Also, take fuel sample from each bag for moisture analysis, see instructions under A.

6. Maintain steady load for 3 to 4 hours. Take readings of kWh-meter each 30 minutes to document load variations. Also, take readings of pressures and temperatures at standard positions.

   For the ANKUR-system, make diesel consumption test according to instructions under A. at least each hour.

7. After 3 to 4 hours, note time and position of kWh meter, fill the gas producer to the same level[16], stir fuel bed and refill to level if necessary.

8. Calculate specific fuel consumption as total weight of fuel supplied from step 4 to step 7, divided by total kWh generated during same period.

9. Continue from step 3 for test at new load.

10. The following loads are recommended for testing and in the following sequence

Day 2	100 %
	60 %
Day 3	20 %
	80 %
Day 4	minimum (internal consumption)
	100 %

Final inspection

The following procedure is recommended:

1. After Day 5, ventilate system, remove fuel bed and inspect for crumbling of charcoal, large slag lumps, caked fuel and similar. Weigh slag lump. Document observations.

2. Sieve charcoal and fill up to original charcoal level. Weigh new charcoal added.

E. Extended operation tests

Extended operation tests, which should have a duration of about 400 hours, are focussed primarily on collection of data on engine contamination, system detorioration and time input of operating personell.

Data shall be collected according to the checklists in annex 3.

Service to system components should be given according to instructions from the vendors, unless observations made during operation indicate a need for unscheduled service. Samples of the lubrication oil of the engine should be taken each 100 operating hours and sent for analysis.

After conclusion of the extended operation test, a second baseline test according to instructions under D. should be carried out.

F. Dust and tar content in the gas

Dust and tar content in the gas should be measured after gas cleaning, just before the gas enters into the engine. The equipment available for these measurements is shown in Figure 4. Experiences from the measurements in March 1991 are summarized in section III.C.

The following procedure is recommended for future tests:

1. Connect the sampling tube in the system just upstream of the engine. If moved from one system to the other, clean the tube and the probe before mounting. If probe has been removed, check that probe tip is located in tube center.

2. Dry a filter cartridge for at least 24 hours at 104 °C, remove warm from oven (not touching with bare hands), pack in three polyethylene bags, and allow to cool down. Weigh immediately. Pack cartridge after weighing in polyethylene bags and do not touch with bare hands.[22]

3. Dry the cooler and beaker and weigh.

4. Install a filter cartridge in the filter vessel. Use a polyethylene bag as glove to avoid touching cartridge with bare hands.

5. Install the gas cooler and beaker.

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22 This can be made for many filter cartridges at the same time. After weighing pick-up of moisture is acceptable and is sufficient to store and handle the cartridges in such a way that no contamination with dirt is possible. Handling and packing cartridges in polyethylene bags should be adequate. If many bags are dried and weighed on the same occasion, the cartridges should be marked <u>before</u> drying and weighing since the weight of the marking colour will otherwise influence the test result.

6. Before starting the generator set, check that the inclined manometer is leveled and adjust so that a zero reading of 50 mm is obtained (at largest angle to vertical) for zero gas flow in the system.

7. Start the generator set and run the system at desired load for at least 30 minutes before sampling is started. The sampling valve should then be closed and the pump switched off. Heating of the filter vessel should be on. Adjust to give a surface temperature of the vessel of about 100 °C.

8. Open sampling valve and check that a positive reading on the inclined manometer is obtained. Open the air valve to the pump and start the pump. Adjust the air valve until the reading on the inclined manometer is back at the zero level chosen (50 mm recommended). Note the reading on the gas meter and the pressure of the sampling gas.

9. Start water flow through the gas cooler. Measure and record water temperature in the water vessel.

10. Adjust the valves before the pump, when necessary, to maintain the reading on the inclined manometer. Note the reading on the gas meter, the sampling pressure and the water temperature each 30 minutes.

11. Continue sampling until at least 0.5 and preferrably 1.0 m^3 have passed the gas meter. Stop sampling by opening the air valve before the pump, stopping the pump, closing the sampling valve and shut off the heating of the filter vessel. Note the final reading on the gas meter.

12. Open the filter vessel and remove the cartridge, again using a polyethylene bag as a glove. Place the cartridge in a clean polyethylene bag.

13. Remove the gas cooler and the beaker[23].

14. Dry and weigh the filter cartridge as recommended under 2.

[23] If time allows, a second cartridge can be positioned in the filter vessel and the sampling continued at the same load using the same gas cooler and beaker.

15. Calculate the dust content in the gas, C_{dust}, as follows:

$$C_{dust}=\frac{Weight increase}{Sample volume}\times\frac{10.197-p_{sample}}{10.197}g/Nm^3$$

where p_{sample} is the sampling pressure expressed in mmWg[24].

16. Dry and weigh the gas cooler. Calculate the weight increase "DWcooler".

17. Weigh condensates "Wcond" collected in the beaker and send condensates for analysis of total organic carbon, TOC.

18. Calculate the tar content in the gas, C_{tar}, as follows:

$$C_{tar}=\frac{DWcooler+1.3\times Wcond\times TOCcontent}{Sample volume}\times\frac{10.197-p_{sample}}{10.197}g/Nm^3$$

This evaluation method implies some overestimation of the tar content, partly because the difference between sample temperature and standard temperature is not considered, see footnote 23 and partly because all tars are assumed to have the chemical composition of phenol.

G. Combustible components in the gas

Measurements of the concentration of combustible components in the gas are not required for achieving the objectives of the project. Such measurements can however be useful for identification of the reason for instance for an unexpected low output of the generator set.

An Orsat-apparatus can be borrowed from NEI Cochranes in Harare for such measurements. Instructions for use of the Orsat apparatus are provided with the apparatus. Samples can be collected from the exhaust of the sampling pump, if the air valve before the pump is closed. It is advisable to make a by-pass arrangement so that the full exhaust pressure from the pump is not supplied to the Orsat.

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24 No correction is made for the deviation of gas sample temperature from standard conditions, since temperature measurements in the sampling gas stream are not practicable at the project. As a consequence, an overestimation of the dust content by about 10% should be expected. This is of no significance for the purposes of this project.

VI. CONCLUDING REMARKS AND RECOMMENDATIONS

A. Strengths and weaknesses of the project

The project idea, i.e to test two different system designs on the same site for identification of weak and strong points in the designs, is very interesting. The results of the project should be of great interest, not only for the PTA-countries but for the international community in general.

The project is well equipped for it's purpose. The spare parts promised for the ANKUR system were still missing in March 1991 however, which may lead to standstill if the parts are not obtained within short.

With some planning and efficient utilization of the personnel, the present project staff should be able to carry out the testing programme proposed here. During tests including determination of dust/tar contents or measurements of the gas composition, two professional engineers should be present. The experiences from the testing in March 1991 shows that one person is not able to make all recordings required on system conditions and run such measurements. In particular tests with the ANKUR-system requires many parallel activities since also the diesel consumption must be measured at regular intervals.

Fuel supply to the project appears to be a problem. Only corn cobs were available in sufficient quantities for extended operational tests in March 1991. One of the priority fuels i.e coffee husk was not available at all.

B. Recommendations

1. The tests at the Nijo Estate should be continued before any of the installations are brought to another site for field testing under conditions where the electricity can be utilized.

2. The occupational health situation at the project should be monitored and measurements made of exposure to carbon monoxide.

3. Further testing of the SES-installation should be focussed on:

   a) Scoping tests with remaining fuels of interest.

   b) Baseline tests with fuels which show promising results in the scoping tests.

   c) Accumulation of engine operating hours with the present gas treatment system, with particular attention to oil contamination and changes in the compression ratio of the engine.

d) Possible simplifications of the gas treatment system including short tests with dust sampling where one or several of the present steps are by-passed and where the last two filters are replaced by the fabric filter designed for the ANKUR-installation.

4. The ANKUR-installation should not be operated with the original gas cleaning system since this will quickly cause deterioration of the engine.

5. In addition to amendment of the gas filtering system for the ANKUR generator set, the following amendments should be made before extended operating tests are made:

   a) installation of a safety filter with moisture separator immidiately before the gas/air mixer;

   b) installation of a more effective gas/air mixer and amendment of the control system to inprove diesel substitution;

   c) amendment of the filtering of scrubber water to avoid deterioration of the ciculation pump

6. Further testing of the ANKUR-installation should be focussed on:

   a) Determination of diesel consumption for straight diesel operation;

   b) Tests required for verification of adequate filter performance;

   c) Scoping tests with remaining fuels of interest.

   d) Baseline tests with fuels which show promising results in the scoping tests.

   e) Accumulation of engine operating hours with the present gas treatment system, with particular attention to oil contamination and changes in the compression ratio of the engine.

7. Efforts should be made to find a cheaper method for preparation of corn cobs for gasification.

VII. REFERENCES

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4. Wood gasification system GE 40.
   Handbook - Operation and Maintenance.
   SES SpA, Via Marino Ghetaldi 64, I-00143 Roma, Italy

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   40 kW_e/50 kVa power generation system - Owners Manual.
   ANKUR Scientific Energy Technologies Pvt Ltd, P O Box 2021, Baroda 390 002, India.

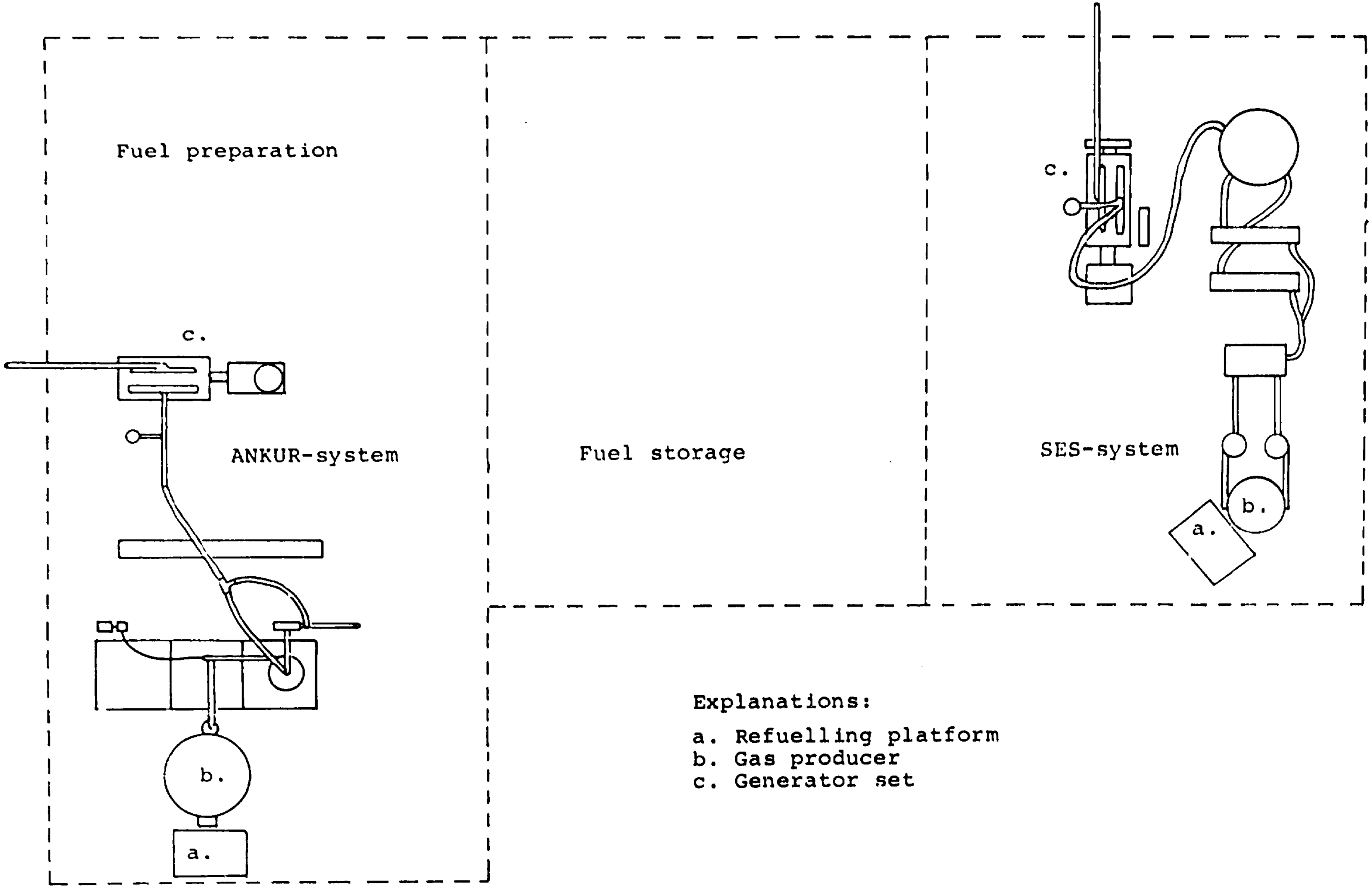
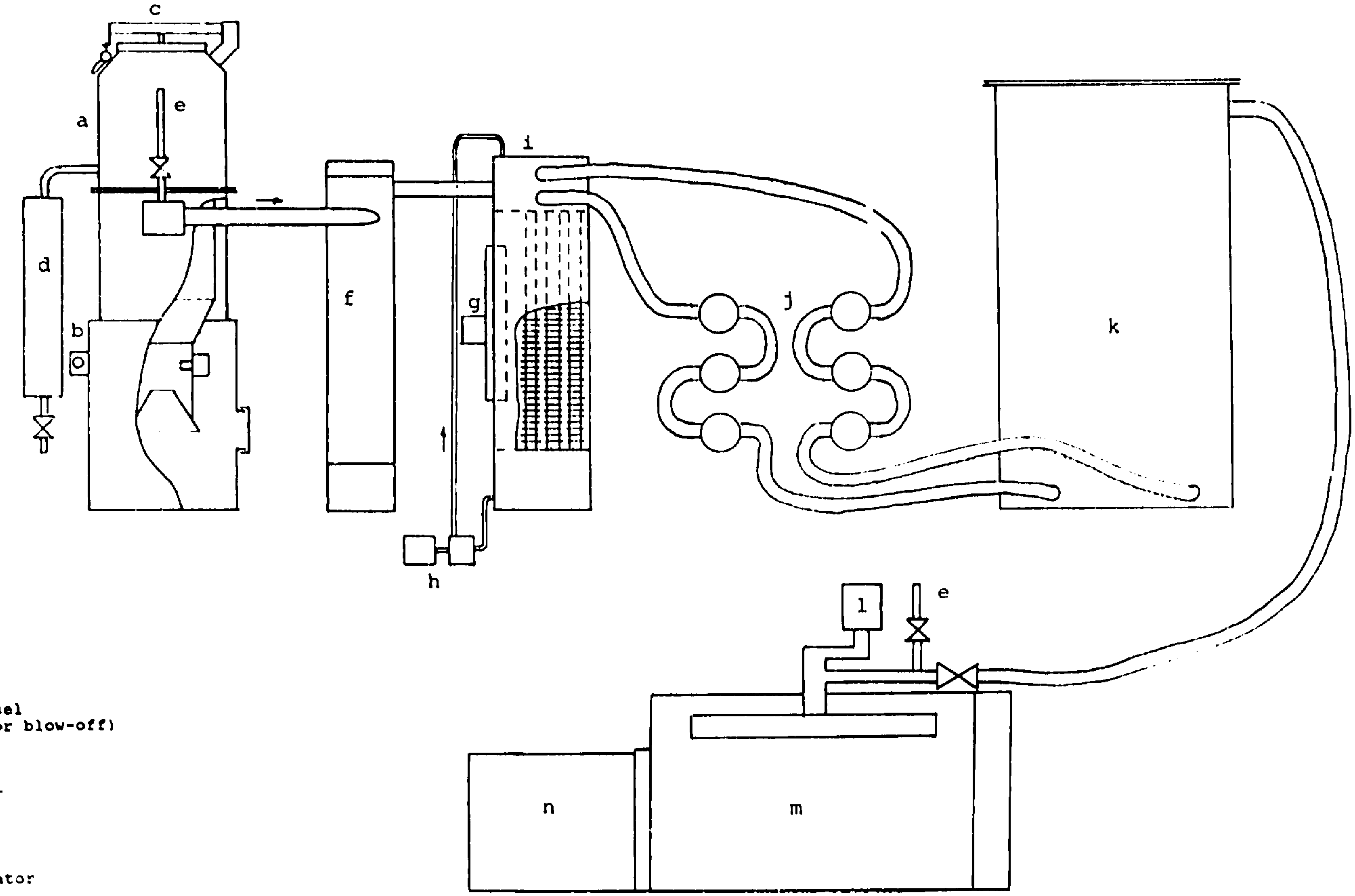


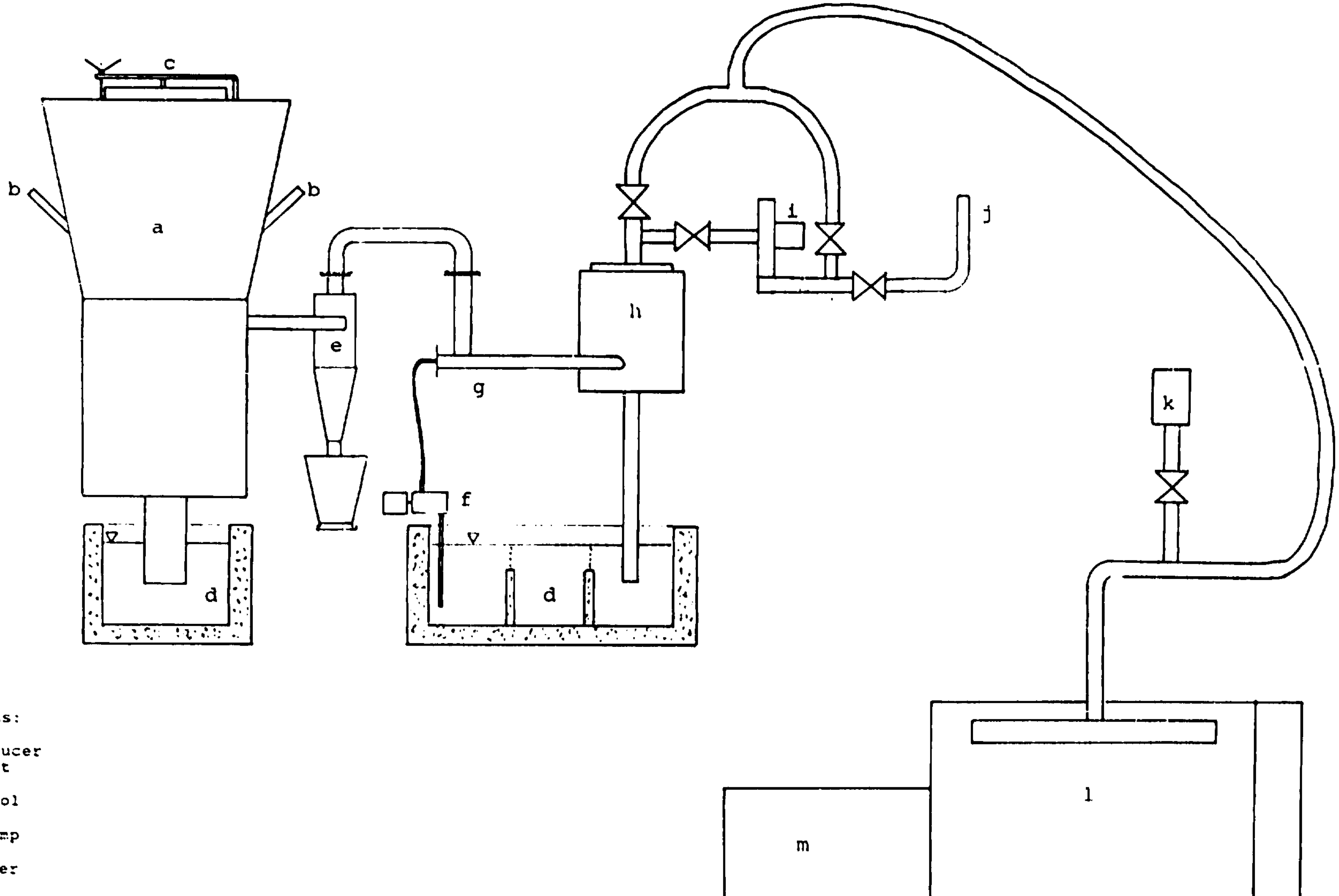
Figure 1. Site layout for the biomass gasifier generator set test at Nijo estate



Explanations:

a. Gas producer
b. Air inlet
c. Fuel lid
d. Condensate vessel
e. Gas exhaust (for blow-off)
f. Cyclone
g. Fan
h. Water pump
i. Scrubber/cooler
j. Baffle filter
k. Bed filter
l. Air cleaner
m. Engine
n. Electric generator

Figure 2. Schematic of the SES biomass gas generator set



Explanations:

a. Gas producer
b. Air inlet
c. Fuel lid
d. Water pool
e. Cyclone
f. Water pump
g. Scrubber
h. Wet filter
i. Fan
j. Gas exhaust (for blow-off)
j. Baffle filter
k. Air cleaner
l. Engine
m. Electric generator

Figure 3. Schematic of the ANKUR biomass gas generator set

Explanations:

a. Sampling tube
b. Sampling probe
c. Valve
d. Cartridge for dust collection
e. Heated filter vessel
f. Inclined manometer
g. Sample cooler
h. Beaker for condensate collection
i. Bed filter
j. Gas meter
k. Valves for flow control
l. Vacuum pump
m. Water tank
n. Bucket for water collection
o. U-tube manometer

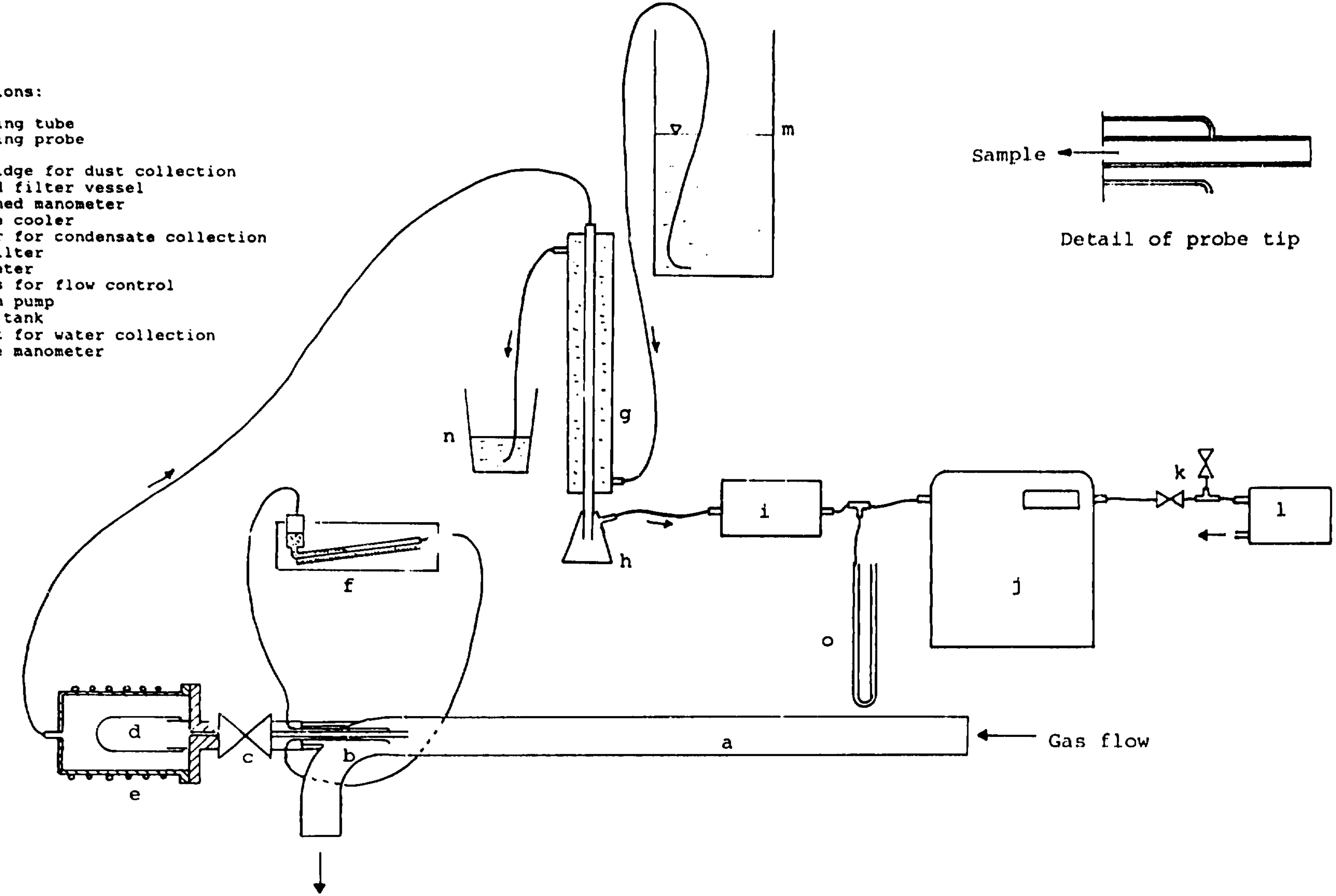
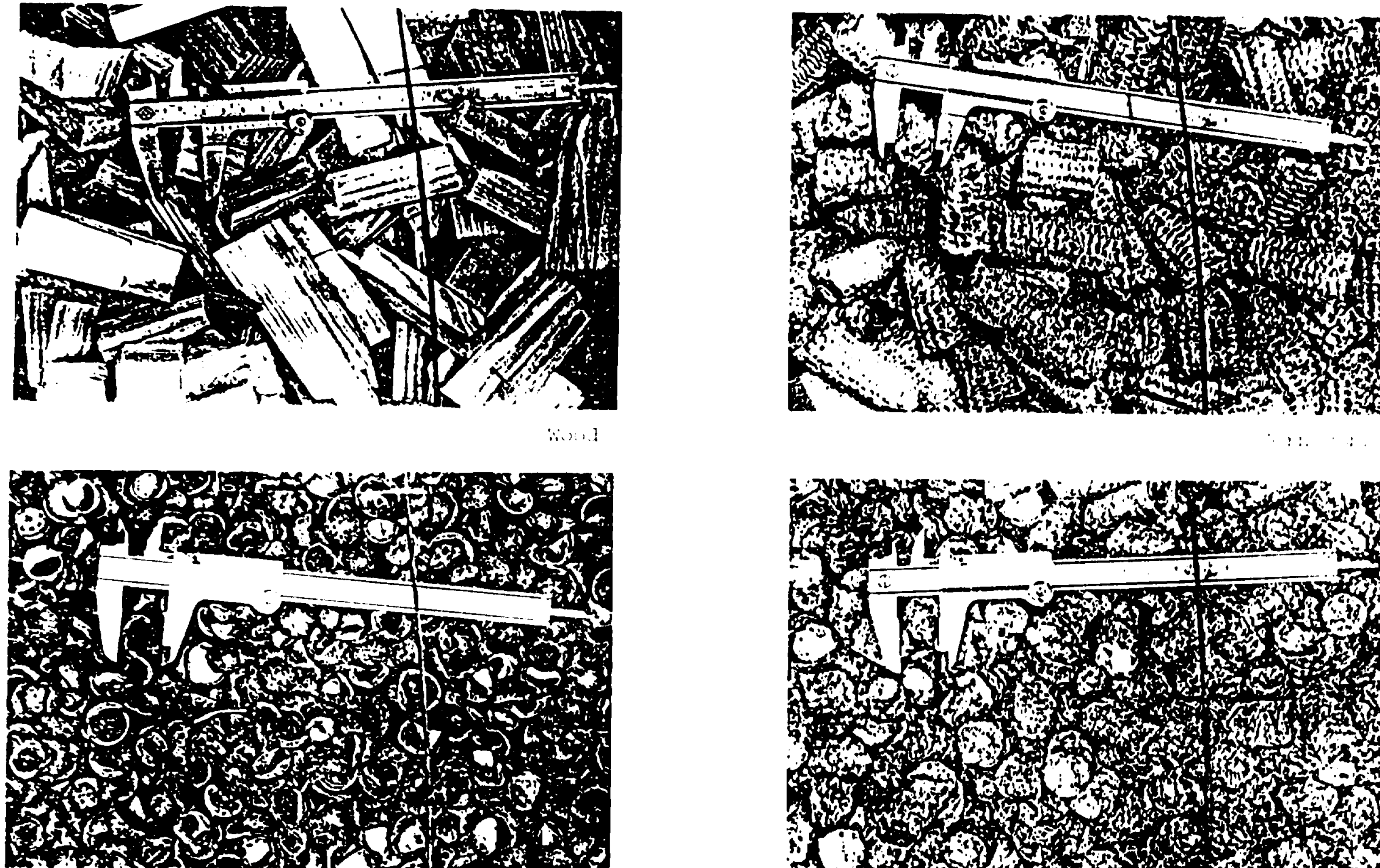


Figure 4. Schematic of arrangement for dust and tar sampling.



Wood

Macadamia nut shells

Figure 5. Fuel samples

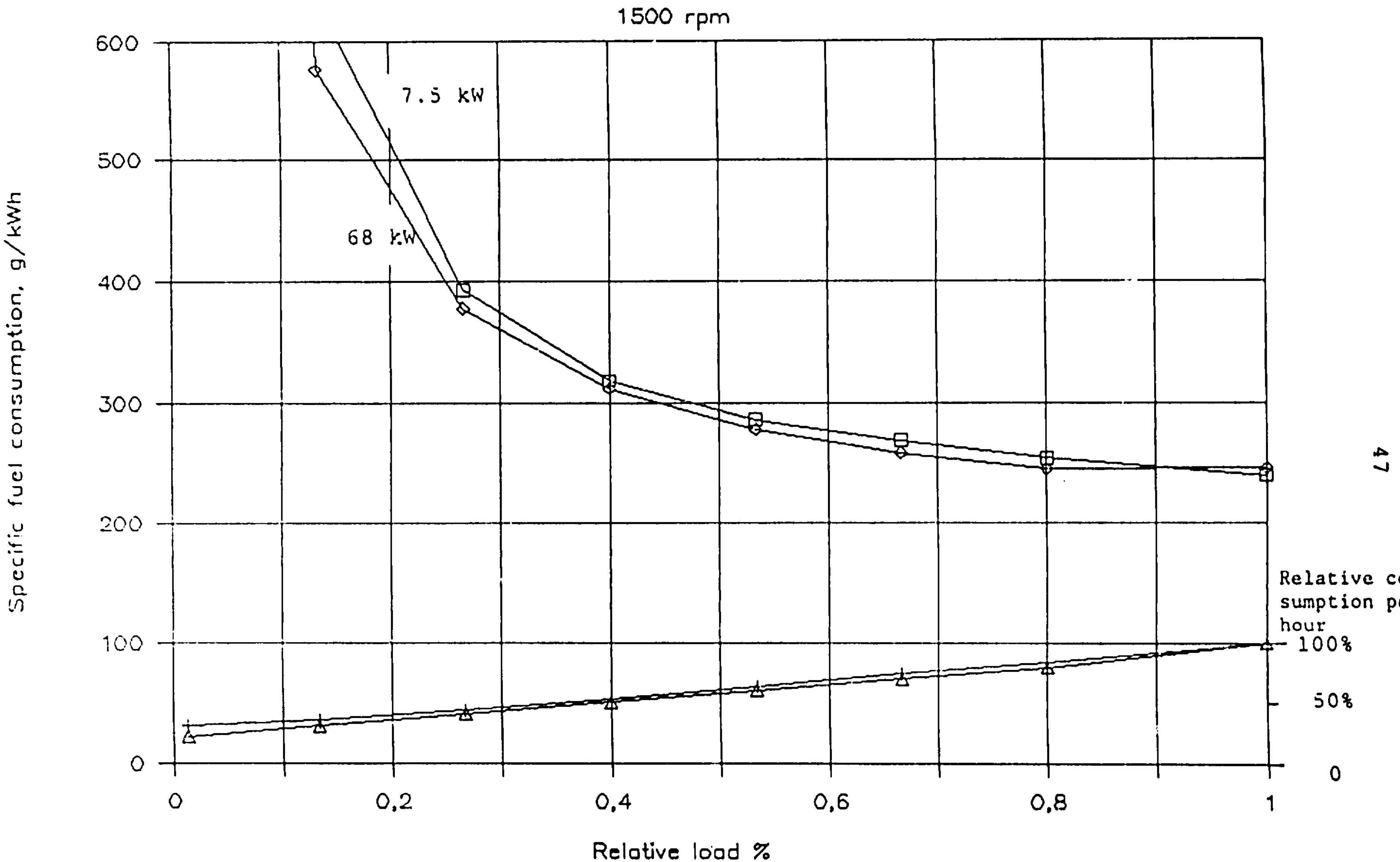


Figure 6. Specific fuel consumption for naturally aspirated diesel engines

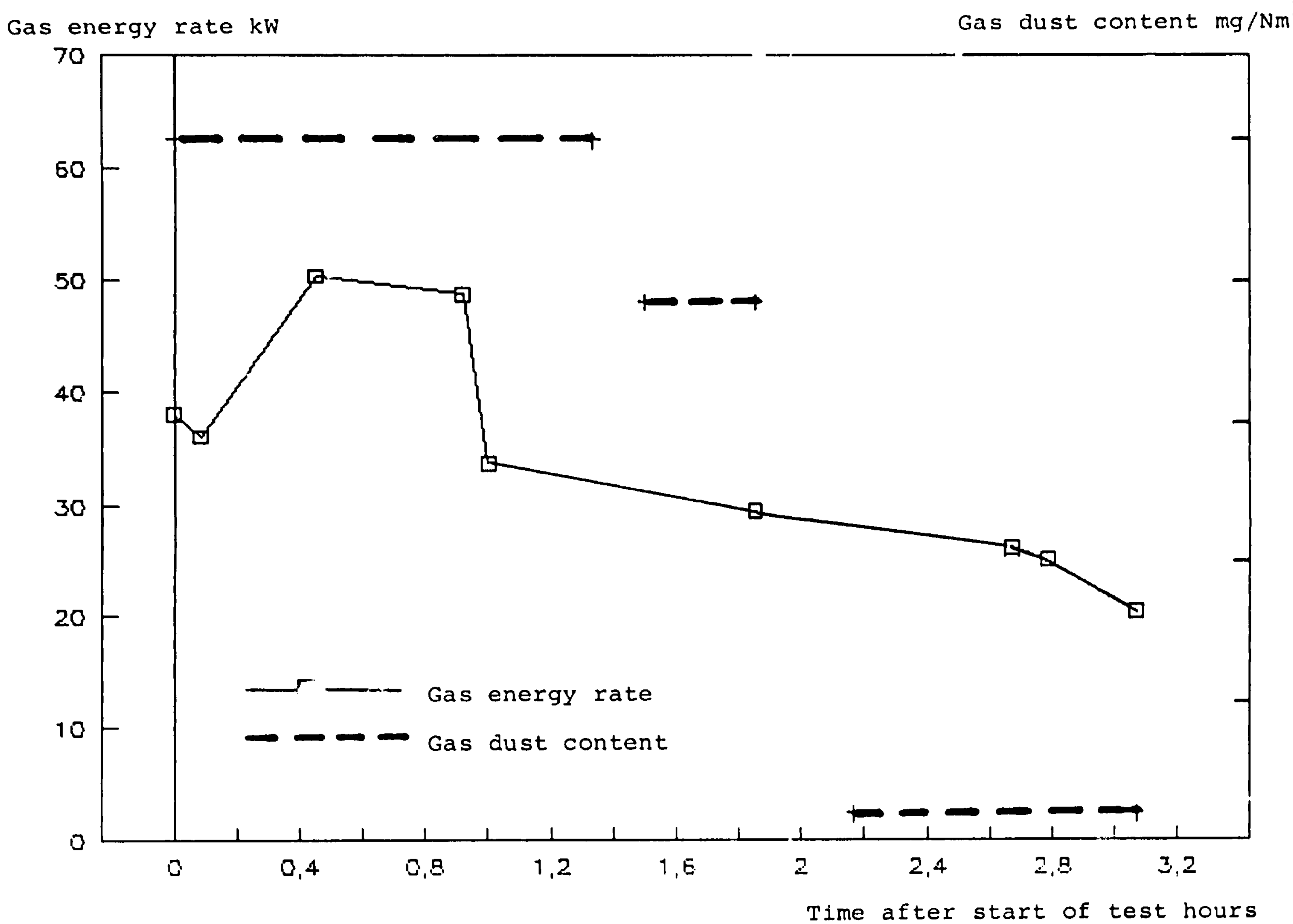


Figure 7. Results of test March 21, 1991 with the ANKUR generator set - Synchronous observations of dust content in the gas and gas generation.

ANNEXES

ANNEX 1

JOB DESCRIPTION

Post title: Short-term expert in gasification technology

Duration: 0.75 m/m

Date required: October/November 1990

Duty station: Harare, Zimbabwe

Purpose of project:

(i) To validate the feasibility of the pilot gasification technology to convert agricultural waste into energy with a view to promoting its wide-spread utilization throughout the PTA subregion.

(ii) To increase the capabilities of the technical and maintenance personnel of the pilot demonstration programme who would also serve as trainers when the technology is applied elsewhere in the subregion.

Duties: The short-term expert will be responsible to assist the CTA for the preparation and organization of the testing programme and training of the operators involved.

In particular, he will:

1. Provide, advise and join the preparation of a detailed programme for testing the installed plants, including planning for collecting agricultural residues as fuel.

2. Elaborate methodology of analysis to be done and provide proposal for pattern of data collection which will support the preparation of guidelines for performance analysis.

3. Assist in conducting test runs of the gasifiers with the different feedstocks on the basis of a developed testing schedule.

4. Support the design of training programme for training of local personnel in the operation, maintenance and trouble shooting of the gasifier technology.

Qualifications: An engineering degree or equivalent with long standing experience in pyrolite gasification.

Language requirements: English

ANNEX 2

OUTLINE OF BIOMASS GASIFICATION COURSE FOR PTA COUNTRIES

OBJECTIVE:

To provide basic knowledge about small scale gasification technology, its potential and limitations.

TARGET GROUP:

Research and development officers responsible for new and renewable energy sources.

QUALIFICATIONS REQUIRED:

Engineering degree (mechanical or chemical).

VENUE:

Nijo estate, 25 km outside of Harare.

TIME:

September 1991, one week (to be confirmed).

CONTACT ADDRESS:

Mr W J Ascough
University of Zimbabwe
P O BOX MP-162
Mt Pleasant, HARARE, Zimbabwe

TEACHERS:

Mr Jeremy Ascough, University of Zimbabwe
Mr Leif Palm, Swedforest AB, Sweden
Mr Temba Munyani, ADA, Zimbabwe

DOCUMENTATION:

Up-date of Swedforest Faerna course manual.

PRE-COURSE PREPARATIONS:

Participants shall bring:

a) A short country report on the expected relevance of biomass gasification in the participants own country;

b) Collection of data on biomass fuel availability and present use in their own country;

c) Information regarding past experiences of biomass gasification in their own country.

PRACTICAL ISSUES:

- Accomodation: Nijo estate (including meals)
- Lecture room at Nijo with blackboard and overhead projector
- Transport to and from Nijo estate
- Participants must be instructed to bring overalls
- Participants must be adequately insured by their own organization

SCHEDULE:

A schedule outline is shown on page 5 of this annex.

LECTURES:

1. Basic chemistry of gasification

   Elementary composition of biomass fuels. Reactions in different parts of the gas producer. Gas compositions at equilibrium. Heating value of the gas. Gas composition resulting from fuels with different moisture content. Release and destruction of condensible organic substances (tars).

2. Gas producer types

   Down-draft gas producers with and without a throat. Up-draft gas producers. Cross-draft gas producers. Gas producers with a fluidized bed. Capacity ranges, fuel specifications and common applications.

3. Process options

   The basic flow sceme. Examples of flow schemes used in operating installations in various countries.

4. Gasifier fuels and fuel preparation

   Properties of different biomass fuels compared to fuel specifications for different types of gas producers. Inputs required for different fuel preparation processes, like size reduction,drying, carbonization and densification. Experiences from use of densified fuels.

5. Hazards and rules for safe operation

   Main hazards to operators and the environment. Carbon monoxide poisoning: Mechanisms, symptoms and treatment. Explosions: Mechanisms, effects and mitigating measures. Rules for safe operation. How to minimize environmental pollution.

6. Engine operation on producer gas

   Possible output of reciprocating engines with different fuels. Application to Otto- and Diesel engines. Conversion options for Otto- and Diesel engines. Downrating and its minimization. Service and maintenance needs. Engine lifetime.

7. Gas cleaning

   Requirements imposed by the engine. Function and performance of dry and wet cyclones, impingement filters, scrubbers, packed bed filters and fabric filters. Examples of gas cleaning systems performance.

8. Economics of biomass gasification

Definition of the competing options. Capital investment required. Equipment lifetimes. Annual capital costs. Costs for fuel, labour, consumables and maintenance. Financial and economic viability of gasifier systems compared to other options (diesel and steam)

9. Experiences from testing of SES and ANKUR systems at Nijo

Results of performance testing. Reliability. Servicability. Desirable modifications.

10. Discussion of experiences from the course relative to situation in PTA countries

Each participant is expected to comment on the relevance of the technology for the energy situation in his or her home country.

PRACTICAL EXERCISES

1. Presentation and inspection of the gasifier installations at Nijo

2. Preparation of flow schemes for the gasifier installations at Nijo.

Both units should be empty, cleaned and partially dismantled. Each participant shall make a flow scheme for both systems.

3. Start-up and operation of gasifier systems at Nijo estate

Participants will be split into two groups. Each group prepares one installation for operation, starts it and runs it for about two hours. Fuel consumption and output to be recorded.

GASIFICATION COURSE - SCHEDULE OVERVIEW

Time	Monday	Tuesday	Wednesday	Thursday	Friday
08 - 09	Participants arrive in Harare and are transported to Nijo Estate	Preparation of process flow schemes for the gasifier systems (P)	Engine operation on producer gas (L)	Economics of biomass gasification (L)	Discussion of experiences from the course relative to situation in PTA countries
09 - 10					
10 - 11			Gas cleaning (L)	Experiences from testing of SES and ANKUR systems at Nijo (L)	Closing of the course
11 - 12	Registration at Nijo				
12 - 13	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
13 - 14	Inspection of gasifier systems (P)	Gasifier fuels and fuel preparation (L)	Start-up and operation of SES/ANKUR system (P)	Start-up and operation of SES/ANKUR system (P)	Participants leave Nijo for Harare
14 - 15					
15 - 16	Basic chemistry of gasification (L)	Hazards of biomass gasification and rules for safe operation (L)			
16 - 17	Gas producer types (L)				
17 - 18	Process options (L)				

Notes:

L lecture
P practical exercise

FORMS FOR DATA COLLECTION DURING OPERATIONAL MONITORING OF SES AND ANKUR GASIFIER INSTALLATIONS

The operational monitoring is based on standardized log-sheets (samples attached), which should be filled in by the operator in charge.

The daily report consists of a summary page and a table for regular recordings of plant conditions at suitable intervals, preferrably not longer than 30 minutes.

In case of equipment failure, a failure report shall be prepared.

Scheduled service and maintenance shall be recorded on a separate form. Change of engine oil shall be recorded in the daily report however. Please notice that oil samples shall be taken for later analysis each time oil is changed.

Finally a monthly plant and occupational safety report shall be prepared.

See also notes on page 9 of this annex.

DAILY OPERATING REPORT

Gasifier system: S.E.S Load[1]: PUMP/DRYERS Date: .... Operator: ....

Checks and service made before operation:

Oil level in engine[2] ....

Oil added liter ....

Engine oil changed[3] ....

Engine oil sample number[4] ....

Charcoal bed level in gasifier[2] ....

Charcoal added kg ....

Water level in scrubber[2] .....

Ashes removed from gasifier[2] ......

Condensates drained[2] ....

Filters cleaned:

Spiral filter[2] .... Scrubber[2] .... Dry filter[2] ....

Preparation time minutes ....

Comments: ....

Observations during start-up:

Time from ignition to operation on load, minutes ....

Smoke from sealings during fan operation[1] yes/no

Summary of daily input and output:

	Before start	After shutdown	Difference	
Accumulated operating hours	....	....	....	(Operating hours for the day)
Accumulated kWh	....	....	....	(kWh generated during the day)

Fuel consumption:

Fuel type: .... Fuel moisture content %[5] .... Total amount used kg[6] ....

Specific fuel consumption dry kg/kWh[7] ....

Comments:

....

....

DAILY OPERATING REPORT (page 2)

Gasifier system: S.E.S Load: PUMP/DRYERS Date: .... Operator: ....

Time of day	Input: Fuel type	Fuel kg	Output: kWh-meter	V volt	A (R) amp	A (S) amp	A (T) amp	System conditions: Gasifier Gastemp out °C	Gaspress out	Cyclone Gaspress out	Scrubber Watertemp out °C	Gaspress in	Bed filter Gaspress in	Gaspress out	Mixer Gastemp in °C	Remarks

DAILY OPERATING REPORT

Gasifier system: ANKUR Load[1]: PUMP/DRYERS Date: .... Operator: ....

Checks and service made before operation:

Oil level in engine[2] .... Oil added liter .... Engine oil changed[3] .... Engine oil sample number[4] .... Charcoal added kg ....

Water changed in ponds: gasifier pond[2] ..... scrubber pond[2] ...... Ashes removed: from cyclone[2] .... Filters cleaned: Scrubber[2] .... Wet filter[2] .... Dry filter[2] ....

Preparation time minutes .... Comments: ....

Observations during start-up:

Time from ignition to operation on load, minutes .... Smoke from sealings during fan operation[1] yes/no

Summary of daily input and output:

	Before start	After shutdown	Difference				
Accumulated operating hours	....	....	....	(Operating hours for the day)			
Accumulated kWh	....	....	....	(kWh generated during the day)			
					Net consumption from tank	Diesel added to tank	Diesel consumed during day
Diesel level in tank, cm	....	....	....		.... liter	.... liter	.... liter

Fuel consumption:

Fuel type: .... Fuel moisture content %[5] .... Total amount used kg[6] ....

Specific fuel consumption dry kg/kWh[7] .... Specific diesel consumption kg/kWh[8] ....

Comments: ....

....

DAILY OPERATING REPORT (page 2)

Gasifier system: ANKUR   Load: PUMP/DRYERS Date: ....   Operator: ....

Time of day	Input: Fuel type	Fuel kg	Output: kWh-meter	V volt	A (R) amp	A (S) amp	A (T) amp	System conditions: Gasifier Gastemp out °C	Gaspress out	Cyclone Gaspress out	Scrubber/filter Watertemp °C	Gaspress out	Engine Gaspress in	Diesel consumption Volume ml	Time sec	Remarks

EQUIPMENT FAILURE REPORT

Installation: SES/ANKUR

Name of equipment:

Date:

Accumulated operating hours:

1. Briefly describe the type of equipment failure experienced.

2. Indicate any suspected reasons for equipment failure.

3. List any materials and spare parts used to repair the equipment.

   Materials:

   Spare parts:

4. Indicate the estimated number of man-hours required to repair the equipment.

   Man-hours:

5. Indicate if the repairs required external technical assistance and if so the number of man-hours required.

   External technical man-hours:

6. Indicate if the equipment failure interrupted the "normal" operating hours of the gasifier and if so the number of interrupted hours or days.

   Interrupted hours or days:

7. Indicate if this equipment component has failed in the past and if so the approximate dates and causes.

   Dates of previous failures:

MONTHLY PLANT OCCUPATIONAL AND SAFETY DATA

Installation: SES/ANKUR

Recording Period: from / / to / /

Please answer "yes" or "no" to the following questions at the end of each operating month. If an answer is "yes" please specify details.

1. Have any incidents relating to exposure to toxic gases or chemicals been reported?

   - number of persons
   - cause
   - location
   - results
   - number of man-days lost

2. Have any plant fires been reported?

   - cause
   - location
   - extent of damages
   - extent of injuries
   - number of man-days lost

3. Have any equipment related injuries been reported?

   - number of persons affected
   - cause
   - location
   - results
   - number of man-days lost

4. If an ambient CO monitor is installed at the plant please record the following information:

   - maximum recorded CO concentration ppm
   - alarm setting ppm
   - number of alarms

SCHEDULED EQUIPMENT SERVICE AND MAINTENANCE REPORT

Installation: SES/ANKUR Date:

Name of equipment/component

Accumulated operating hours:

1. Briefly describe the type of equipment maintenance performed.

2. List any materials and spare parts used in the maintenance operation.

3. Indicate the estimated number of man-hours required to perform maintenance

4. Indicate if the maintenance required external technical assistance and if so the number of man-hours required, as well as the costs involved:

   Man-hours: Cost: ZIMD

5. Indicate if the maintenance interrupted the "normal" operating hours of the gasifier and if so the number of interrupted hours or days.

6. When is the next scheduled maintenance for this equipment component.

NOTES TO DAILY REPORTS

1. Cross over the alternative that is not applicable

2. Write signature on dotted line to verify that check was done.

3. To be done at intervals according to engine manual

4. Engine oil sample shall be taken for analysis each time oil is changed.

5. Wet basis moisture content. Sample to be taken from each second fuel charge for determination of moisture content

6. To be calculated from data on page 2 of the daily operating report

7. Calculate dry kg of fuel supplied by multiplication of total fuel amount by (1-F) where F is the moisture content. Calculate specific fuel consumption by division with kWh generated during the day.

8. Calculate from diesel consumption in liters, using diesel density 0.87 kg/liter