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Demonstration Programme on Use of

Indigenous Biomass Resources for Meeting Energy Needs

Phase III

Project XA/RAF/90/602

FINAL REPORT

Based on the work of L Palm,
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Vienna

SUMMARY

In 1985 UNIDO, under the programme for the Industrial Development Decade for Africa, started the Demonstration Programme on Use of Indigenous Biomass Resources for Meeting Energy to examine the technical and socio-economic viability of generating energy for rural use by means of gasification of agricultural residues.

The main purpose of the project was to validate the feasibility of the pilot gasification technology with a view to promoting its utilization in the PTA subregion and to increase the capabilities of the technical and maintenance personnel by carrying out in plant training and organizing a subregional training wortkshop.

It can be concluded that results and experience gained at the project certainly justify the inputs made and have provided the community with very valuable information and even proven that the technique can become technically and economically viable under certain conditions, conditions likely to be found in rural applications. The development, especially for most of the developing countries, of a new technique, is an ongoing process with repeated testing and modifying. The reader is asked to have a glance on the development of the automobile - still an ongoing process.

The third phase of the Programme started mid 1990 and was terminated by the end of 1991.

The experience at the project, when neglecting the initial bottlenecks and shortness, and international experience clearly indicate that the most common types of gas producers, downdraft gas producer with V-type throat, can certainly be used for gasification of selected agro wastes, in this case, corn cobs. This type of gas producer is normally called "Imbert type".

The tests further proved that a gas cleaning train built on a water scrubber, for tar elimination, a modification of the original Ankur gas cleaning train, is a simple and technically viable solution.

The economical evaluation indicated that the original design of the SES's gas producer (and gas cleaning train) results in an investment cost, even when locally manufactured, which can not be justified. The investment cost of the Ankur plant was approximately one fifth of the SES plant and would have been comparable to a diesel plant provided functional.

To simplify the manufacturing and to reduce the manufacturing cost, the SES's gas producer has been streamlined and equipped with a turnable grate, all in line with a traditional Imbert type gas producer.

For a comparison, a cost estimation on manufacturing of the streamlined equipment in Sweden was carried out. The estimation gave an investment cost of the

gasification equipment (gas cleaning and gas producer) to approximately half of the Sub-contractor's cost estimation, based on the Zimbabwean conditions and on the original design of the SES's gas producer.

The economical evaluation, based on the alternative cost estimate, clearly indicated that the technique is economically viable, provided the price of the diesel "free in tank of the engine" is approximately 50% higher than the price of the diesel at a filling station in Harare (US$ 0.25 per litre) and that the cost of the waste is not higher than US$ 20 per ton, including the cost for feedstock preparation.

These conditions are most likely to be fulfilled for rural installations, provided the plants are installed where feedstock can be supplied by minimal transport needs, thus with a big potential to alternative means of power generation.

The fuel preparation cost at the pilot project amounted to about US$ 10 per ton corn cobs.

The tests carried out at the project further showed that out of the for this project identified feedstocks, namely corn cobs, groundnut shell pellets and coffee husks, only corn cobs was a suitable fuel for the actual type of gas producer. It was also found that the required feedstock preparation is limited to cracking the cobs into two to three pieces.

The tests clearly indicated that the original gas cleaning equipment of the Ankur plant was insufficient and that the performance of the plant was not good enough for fuelling an Otto engine generator set with an electrical output of 40 kW. The SES fulfilled this requirement and the plant supplied a quality of the gas where limited excess wear of the engine can be expected.

The shortness in the gas cleaning systems, SES's too expensive and Ankur's not functional, have been considered and a modified gas cleaning equipment have been designed and is described in this report.

The Pilot Programme has to a great extent included training, on different levels and at different stages, resulting in a large number of people that have received the possibility to be trained. On the same theme and to promote dissemination of the technique, a PTA Gasification Training Course was carried out at the project.

Training, which is a very important factor for a successful introduction, has been considered separately in an annex to this report.

The experiences drawn are based upon a relatively limited number of operating hours (approximately 1,000 hours). It is therefor envisaged that both plants are operated for 2-3,000 hours further to establishe the very important long term experiences.

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All the staff involved, from the Project Director to General Labourers, all of whom, without their devotion, care and support, this project would not have been the success it turned out to be.

ABBREVIATIONS

ADA	Agricultural Development Authority
DOE	Department of Energy of MEWRD
Hz	frequency
kW_e	kW electricity
LF	Load factor
MC	Moisture content
MEWRD	Ministry of Energy Water Resources and Development
mmWg	mm water pillar
PD	Project Director
PM	Project Manager
PO	Project Officer
R&D	Research and development
ToR	Terms of Reference

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1. INTRODUCTION

1.1 BACKGROUND

In 1985 UNIDO, under the programme for the Industrial Development Decade for Africa, through a project RP/RAF/85/627, later on called Phase I of the Demonstration Programme on Use of Indigenous Biomass Resources for Meeting Energy Needs, carried out a pre-feasibility study /1/ to examine the technical and socio-economic viability of generating energy for rural use by means of gasification of agricultural residues.

The study identified coffee husks/parchment, densified groundnut shells and shredded and then densified corncobs to be employed as fuel for the Demonstration Programme.

It was expected that the pilot programme would provide a sound data base for the application of this source of energy in the PTA subregion.

Prior to undertaking the study preliminary investigations were carried out and on the basis of the information and statistics made available for the study, Zimbabwe was selected as the host country for the pilot plant.

The pre-feasibility study, /1/, which included detailed plans for the following steps of the programme, as well as to which feedstock to be used, has formed the basis for future work.

The study proved the concept practicable and in 1988 UNIDO carried out another project, XA/RAF/88/681, which has been called Phase II of the Demonstration Programme.

The output of Phase II was to have a fully operational pilot gasification plant, with design drawings and production process specifications of equipment compatible for local manufacturing, installed, de-bugged, the technical personnel trained and a description of the pilot programme to be carried out as Phase III, all completed by end of 1989.

The implementation of Phase II was started in April 1989, when the Chief Technical Adviser was appointed. Due to the available time the second phase had to be streamlined.

The proposed densification of the agricultural waste, before gasification, was at this stage eliminated from the programme. The reason was (is) that densification (briquetting/pelletizing), is an expensive process which results in a feedstock price that can not be justified for producer gas operation in the actual scale. The identified wastes do not contain natural binders and it was assumed (based on international experiences) that the briquetted/pelletized fuel would not withstand the gasification process unless expensive binders were added. Another reason to the exclusion was that the frames of Phase II were not either enough to include densification.

The second phase was started with CTA's familiarization mission to Zimbabwe /2/ to re-activate the organization in Harare.

This mission was followed by a combined Study, Training and Equipment Selection Mission /3/ which ended in the recommendation and purchasing of a S.E.S. GE-40 gasification unit from Italy, to 100 % fuelled on producer gas and a second gasification unit, Ankur's dual fuelled biomass gasifier BG-40, from India.

A short term consultant was appointed in April 1989 to carry out the Potential Sources of Initial Gasifier Design /4/ for the project and for the planning of the combined study and selection tour together with the CTA.

The plants arrived (after delays in shipping) in Harare in the beginning of December and were installed at Nijo Estate on the outskirts of Harare. The plants were preliminary tested and commissioned, before the end of the year, with assistance from an Engineer from each respective company and with the assistance from Cochrane Engineering (Pvt) Ltd.

The S.E.S. plant was the only plant connected to the load, a water pump for an irrigation scheme at the Estate, due to the delays with the civil works. After short tests, it was decided, due to the fact that no operators had received the opportunity to be fully trained, to close down the project and prepare/preserve the equipment for the inevitable intermediate period to come, before the next phase was funded and could be implemented.

Most of the outputs for Phase II were fulfilled, the key people were recruited and the plants were ready for pilot testing during the following phase.

The statistical work was decided to be completed at a later stage (Phase III) and the contract for the Project Director and the Sub-contractor, (Cochrane Engineering (Pvt) Ltd) was shorter than originally proposed, simply due to the limited time. The time factor also streamlined the output related to the testing and specifying of the final design and the following phase.

After presentation of the final report from Phase II /5/, Phase III of the Demonstration Programme, Project XA/RAF/90/602 started in July 1990. The project activities at site started in August with the CTA's mission to Zimbabwe, summarized in CTA's 1st Mission Report /6/.

The second phase involved, in brief, all the necessary work up to the beginning of the test runs.

The duration of the third phase was 16 months and the whole Demonstration Programme ends with a report (this one).

Interim reports, Quarterly Report /7/ and Third Mission Report /8/, have earlier been presented, by the CTA, on the third phase.

For assisting in the testing and evaluation of the feedstock and the gas producers, UNIDO appointed a Short-term Consultant in March 1991. The consultant presented a technical report /9/ to UNIDO, together with Outline of Biomass Gasification Course for PTA-countries.

The notes from the combined seminar/course which was conducted by the CTA, the Project Director and the Project Operator in September 1991, have been reported to UNIDO /10/ and will be distributed to the participants.

UNIDO appointed another consultant, Statistician, for six months, to carry out a market survey and potential for the local manufacture of gasifiers in the subregion. The results of the statistician's appointment have been presented in a report to UNIDO, Crop Wastes as Feedstock for Gasification /11/.

As earlier mentioned UNIDO appointed a Sub-contractor for assisting in the installations of the pilot plants. The same Sub-contractor was appointed during the duration of the third phase for assisting the project with maintenance, modifications and in technical matters as well as in proposing an appropriate gasifier unit for operating under local conditions. The Sub-contractor has submitted a final report to UNIDO /12/ on its engineering services.

Besides all the reports mentioned above, the Project Director has continuously submitted Monthly Progress Reports to UNIDO /13/.

The CTA attended, upon request by UNIDO, a meeting in Lusaka in September, 1991, to inform the PTA Secretariat, under the theme to further promote the dissemination of the technology to the other PTA-countries. The Demonstration Programme experienced a very big interest.

This report, which is written from the CTA's point of view and after receiving the Sub-contractor's and the Statistician's reports, is the final report on Phase III and the present Demonstration Programme.

Various discussions, based on the interest experienced, have been held on possible alternative proposals to supported extensions and spin-off activities, but it should be mentioned that nothing has been decided upon.

1.2 AIM OF THE PROJECT

Since the two first phases of the demonstration programme have been elaborated in the respective final reports /1 and 5/, this report/project mainly covers/refers to the third phase, unless otherwise mentioned.

The aim of this project, which can be seen in detail from the project documents in Annex A to D, can be illustrated by the four anticipated outputs:

- A fully operational demonstration gasification programme in the PTA subregion.

- A report containing description of the design and fabrication of the gasification technology, the characteristics of operation of the gasifiers indicating the design modifications necessary for optimal functioning with the different agricultural resources/feedstock; economic analysis/data of the field trial of the technology.

- A report on marketing survey and potential for the local manufacture of gasifiers in the subregion.

- A core of eleven operation and maintenance personnel trained in all aspects of gasifier operation, monitoring, engine maintenance, fuel preparation, load connection and management of overall operations.

Guidelines for a training programme is given in Annex E.

2. TECHNICAL CHARACTERISTICS

2.1 SYSTEM DESCRIPTION

A detailed description of the two plants can be found in the Sub-contractors report to UNIDO /12/, including drawings.

The confidentiality, as well as to reduce duplication of information, has guided the presentation.

6.1.1 The S.E.S plant as received

The layout of the SES model GE 4J gasification unit is attached in Annex F, together with some photographs of the plant.

System specification

The following system specifications were provided by the manufacturer:

Primary biomass fuel	Wood
Acceptable MC	15–25%
Max fuel size	5x5x5 cm
Rated capacity:	
Gas producer	98.000 kcal/h
	120 m3/h
Generator	40 kW max
	35 kW rated
Performance at rated load:	
Gas producer efficiency	75–80%
Fuel consumption	1.3 kg/kWh
Internal electricity consumption	2.2 kW
Pressure loss (gas treatment)	60 cm Wg
Possible feedstock:	Corn cobs, corn cobs/wood mixed with other agricultural residues with low ash content.

Gas producer

The gas producer is of the down–draft type (Imbert) with a condensation jacket in the hopper. The throat is of V–type with a throat diameter of 125 mm. Air is supplied (sucked) through 5 air nozzles, positioned about 100 mm above the throat. The gas producer is not provided with a grate, and the charcoal bed is resting on the bottom of the gas produced. The height of the reduction zone is approximately 200 mm.

The gas producer is equipped with ports for ash removal and for filling of the charcoal into the reduction zone.

The fuel is fed manually through a top lid of the hopper.

A pressure fan is temporarily connected to the air inlet during start–up and the gasifier is started by inserting burning wood shavings, paper etc into the air inlet and blowing the fire (by the fan) into the throat. The fan is operated, and the raw gas flared off from the gasifier, until the heat is built up. When the quality of gas is good (blue, clean flare) the gas is let into the gas treating train and flared off just before the engine. The purpose is to fill the system with clean gas up to the engine.

Gas treatment

After the gas producer the gas passes through two parallel swarf filled bed filters, a scrubber equipped with forced cooling, a disk type baffle filter system and finally, through a large bed type filter filled with wood wool or wood chips.

Gas mixer

The producer gas and air is mixed just before the inlet manifold in a gas mixer consisting of butterfly valves linked with turnbuckles for setting the air–gas ratio. The mechanical governor reads the rpm and adjust the valves through a linkage system accordingly to maintain 1500 rpm (50 Hz).

Engine

The engine is a six cylinder FIAT–IVECO diesel engine type 8361i, displacement 8.102 dm3, converted to spark ignition for producer gas. Compression ratio taken down to 11:1 by modified pistons. The maximum power rating on diesel operation, before conversion, is 71 kW at 1500 rpm.

Generator

The generator is a 3 phase, 78 kVA (cos phi 0.8) 380/220 V AC generator from Tessari, with frequency 50 Hz and 1500 rpm.

The generator and engine is skid-mounted as ordinary standby generator sets.

Control

Besides the ordinary controls, mounted in a lockable box which is fitted to the generator set, a kWh meter was added for reading the energy supplied.

System instrumentation

Besides the standard control panel, the producer gas equipment is equipped with thermometers and taps for pressure gauge (plastic hoses or U-tubes) or gas sampling.

2.1.2 The Ankur system as received

The layout of the Ankur model BG 40 gasification unit is attached in Annex G, together with some photographs of the plant.

System specification

Dual fuel operated diesel/producer gas engine

Primary biomass fuel	Wood/woody waste
Acceptable MC	5-20%
Max fuel size	125 mm
Rated capacity:	
Gas producer	100.000 kcal/h
	100 m3/h
Generator	40 kW electricity rated
Turn down ratio	1:3
Performance at rated load:	
Gas producer efficiency	70-75%
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%

Gas producer

The gas producer is of downdraft type. The throat is an integral part of the conical hopper and has a diameter of approximately 120 mm. Air is supplied (sucked in) through two inclined pipes which also constitute the air nozzles. The height of the reduction zone, from the fixed grate to the throat, is approximately 48 cm. Below the grate, the gas producer extends into a chamber with a conical bottom extended with a pipe. The pipe ends in a water pond (water lock), from where the ash is removed manually.

A vibrator is connected to the gas producer to agitate the feedstock and the ash removal.

The engine is started on diesel and should be run on diesel until the engine has reached normal operation temperature.

The gas producer is lit by holding a flare to the inclined pipes and during start-up a centrifugal fan is used to suck the flare and air into the gas producer. The raw gas passes trough the gas cleaning train, which is also switched on during start-up (see below), and is flared off until the gas is of good quality.

When the gas is clean, the manual valves (cock valves) are gradually adjusted by closing the flare-off and opening the gas supply to the engine.

Gas mixer and speed control

The gas and air is mixed in a T-pipe. The pipe from the air-filter is equipped with a manual valve (cock) for balancing the pressure drop over the gasifier system and the air-filter and thereby set the ratio of the gas-air entering the inlet manifold.

There is one manual valve (cock) before the centrifugal fan and one similar valve on the pipe to the flare-off and one similar valve on the main supply pipe. The gas flow is controlled manually by these switch-over valves.

The instructions given by the manufacturer's representative during the installation was, that during heavy loads, high pressure drops over the gas producer or low quality of the gas, the fan could be continuously run as a booster fan and its supply (pressure) adjusted by the shift-over valves. The setting of the valves, including the valve on the pipe from the air-filter, is done manually. The smoothest operation is judged from the sound and exhaust smoke from the engine. The combined mechanical governor and diesel pump controls the speed by controlling the amount of diesel injected.

For low load, good gas and low pressure drops the fan is switched off and the switch-over valves fully open for the main flow. The air-gas mixture is now balanced for smoothest operation by adjusting the valve at the air filter.

To check that maximum diesel replacement is achieved, the diesel tank is equipped with a measuring cylinder and a switch-over tap. By clocking the consumption, or when experienced observing the level of the diesel in the measuring cylinder, the diesel replacement can be calculated or judged.

Gas treatment

From the gas producer the gas passes a cyclone, a venturi scrubber and finally a combined water separator and a fabric filter. The water separated after the scrubber and from the filter box is drained through pipes submerged into a sedimentation pond. Scrubbing water is recirculated, after a two step sedimentation, by means of a centrifugal pump.

Engine

The engine is a six cylinder, four stroke Leyland-Ashok diesel engine, type ALU 370. The displacement is 6.075 dm3 and the compression ratio 16:1.

The engine is equipped with a mechanical speed governor controlling the diesel injection and for dual fuel operation, the air valve is closed by the operator until smoke is visible in the exhausts.

Generator

The generator is a brushless 3 phase, 50 kVA (cos phi 0.8), 415 V and 50 Hz and 1500 rpm AC generator from Kirloskar Electric Co Ltd India.

Control

The set is equipped with the most elementary control panel in a separate box mounted on a wall. The panel on the engine has a temperature, a oil pressure and a rpm/hour meter.

System instrumentation

The plant was originally equipped with three pressure taps and a level gauge for the fuel tank.

2.2 PLANT PERFORMANCES

2.2.1 Plant performances as received

Both plants are initially designed for wood as primary fuel. However, both manufacturers ensured, during the Equipment Selection Mission /3/, that their plants could operate on corn cobs but with a slight derating. Other woody agricultural fuels, with low ash content, would likely be acceptable, preferably in mixtures with wood or maize cobs. Both manufacturers stressed that out of the fuels identified for the demonstration programme, only maize cobs had been systematically tested.

During the commissioning, the SES plant peaked, on maize cobs, over 35 kW, which is the rated capacity. Under good conditions, very dry cobs and when using carpentry dry wood, the peak capacity (40 kW) could be achieved.

The plant was easy to start if the instructions were followed and the speed control automatically maintained the speed (1500 rpm) from no load to rated load.

The attention is limited to filling of the feedstock and de-ashing and cleaning of the gas cleaning equipment.

The plant was indeed handed over in turn-key condition and ready for operation when the SES engineer (appointed for the installation/commissioning) left.

The Ankur plant could not be loaded during the commissioning due to delays in the civil work and the tight time schedule. Priority was paid to the SES plant due to two reasons: The SES plant was designed (and completed) for quick and simple installation. The civil work for the Ankur plant was not completed and some minor parts were needed before the plant could be assembled. The concrete/brick made water ponds had to be modified (though made according to earlier received drawings) since the dimensions did not fit the plant.

However, the plant might peak 40 kW, since the gas-air-diesel regulation operates (automatically through the mechanical governor) in such a way that, provided the oxygen (air) flow is enough, the engine will maintain the capacity on the expense of high diesel consumption. There are limited possibilities at present (not enough load) at the project to gradually step up the load to test the plants at higher loads. The estate's pump station, which initially consumed 30-40 kW, is now consuming over 40 kW and faced its own problems. The available load was the driers and the workshop.

The automatic speed control can only cover smaller load variations within the actual load interval. The air-gas-diesel ratio, which is controlled manually by a valve (cock) on the air pipe, can only be set for a fixed load, rpm and quality of the producer gas. As soon as any of these parameters changes a new setting is needed. Besides these parameters, the pressure drop over the gasifier varies during operation (and with feedstock) and the pressure drop over the air filter and especially over the gas treatment train varies with flow, temperature, degree of dust collected on the filter etc. It is obvious that it is very difficult to maintain optimal conditions and a skilled and all the time present operator is needed. However, the engine does operate without any bigger problems, for smaller deviations from optimum, but on the expense of low diesel replacement.

On top of this; the diesel replacement can only be determined by simultaneously reading the kWh produced and diesel fuel consumed over a certain time. This diesel consumption has to be compared to what the diesel consumption would have been in (full) diesel operation during exactly the same operation conditions. However, with time, a good operator gets the "feeling" of how good the diesel replacement is, but he can never know exactly unless following the procedure above.

The Ankur Engineer's instructions, during installation, was that the gas flow could be set by measuring the air velocity in the pipes supplying the air nozzles, either by an anemometer or by sensing with the fingers. The velocity should be about 15 m/s for best operation of the gas producer.

It is obvious, that this type of regulation is only applicable to operation under practically constant load (in a laboratory).

Finally, it has to be mentioned and stressed that, the aim has never been to have a dual fuel operated plant for the demonstration programme (the actual Ankur plant is designed for dual fuel operation). During the selection, ordering and purchasing of the equipment is was agreed that the manufacturer should try to supply on Otto engine, but with clear reservations that a dual fuelled plant would be supplied if Ankur's engine supplier could not supply retrofitted diesel engine within the tight time frame available. The Ankur system was considered to apply other technical design solutions, which were of interest for the programme, and thereby justified the purchasing.

2.2.2 Test results

The initial tests results were presented in the Short-term Consultants report to UNIDO /9/ and some of the test results are presented in Annex O. The SES and the Ankur plant had then been operated for approximately 300 and 160 hours respectively before the tests.

The plants were operated for approximately another seven months before the official close down of the third phase of the programme. The SES reached over 1,000 hours of operation and the Ankur plant reached approximately 700 hours of operation. The accumulated hours would have been higher unless the project had faced labour accommodation and transportation problems.

The operation during the last half year in general, confirmed the findings and test results earlier achieved. The goal should now be to operate the two plants for 2–3,000 hours more to be able to establish lifetimes and long term experiences.

2.2.2.1 Tests of the proposed fuels

The three types of fuel identified for the pilot programme were corn cobs, groundnut shell pellets and coffee husks. See Annex O for test results.

Coffee husk

The coffee husk was not considered a suitable feedstock for the actual type of gas producers, downdraft gas producer with V–type throat. The available coffee husk, which was studied during a field study to Banket, shows many similarities to rice husk and can likely be successfully gasified in gasifiers of the type used for rice husk, open core gasifiers with moving grate. The judgement was done without carrying out any tests at site, but based on international experiences.

Corn cobs

The main feedstock used, for both plants, during the course of the programme was corn cobs. This was expected and the fuel collection guided accordingly.

It was found necessary to prepare the maize cobs by cracking/cutting the cobs into three pieces, not to cause bunker flow problems in the SES gas producer. The Ankur gas producer can likely swallow cobs cut into only two pieces, perhaps even whole pieces, if one can find the right frequency and amplitude of the vibrator fitted to the gas producer. The moisture content, of the cobs received varied from 10 to 16% and suitable without further drying.

The manual cutting/chopping of the cobs is a labour intensive operation, but does not require any investment in equipment nor any skilled labourers. The fuel preparation cost, included chopping and filling up day store, amounted to 51 Z$ per ton (which is equivalent to about 10 US$/ton).

Both plants performed, in general, as expected on corn cobs.

It was found that the char generated during the gasification of corn cobs is less than char consumed during the reduction, i.e charcoal has to be added. In fact it has been established that the charcoal bed have to be emptied and refilled after 36 hours of operation. The usable char is sieved out and fed back toether with new charcoal. This equals to a charcoal consumption, for the SES gas producer, of approximately 0.08 kg/kWh. It should be mentioned that, these figures have been verified for the SES plant but the Ankur plant shows similar experiences.

Groundnut pellets

The groundnut pellets which had a moisture content of approximately 10% caused high pressure drops over the gas producer already from start and increased continuously. After a few hours of operation the engine could barely meet the load.

The fuel caused big slag lumps in the throat zone, which is related to the fuel property (ash content, melting point) and to the likely high soil contamination.

The initial high pressure drop could be eliminated by increasing the diameter of the pellets, i.e use briquettes. However, the rapid increase of the pressure drop clearly indicated that the pellets disintegrated/fell apart (could be verified by inspection) during the gasification process. The disintegration is likely to occur for briquettes unless the briquettes (and pellets) are manufactured under higher pressures and by using good binders.

It was concluded that groundnut pellets are not a suitable fuel for the present types of gas producers.

2.2.2.2 Tests of other wastes

Besides the mentioned fuels, a few shorter test with Macadamia nut shells and Cotton stalks were carried out. See Annex H and O for the fuels tested.

The experience from the test on Macadamia nut shells were very similar to the test on groundnut shells; high pressure drops and big slag lumps in the bed. It was concluded that the Macadamia nut shells were not a suitable fuel for the actual types of gasifiers. It has to be stressed that the nut shell received were very contaminated with soil (sweep-ups) and further tests on clean shells should be carried out.

The plants were also operated, from time to time, on carpentry wastes (off cuts, splinters etc from a crate manufacturing plant mainly), i.e wood wastes. The plants performed as expected when the size distribution was as specified by the suppliers.

A shorter test on cotton stalks was also carried out, but not in a systematic way and with limited documentation to draw any deeper conclusions. The cotton stalks caused bunker bridging in the SES plant. The Ankur plant showed less bunker flow problems, due to the fuel agitation by the vibrator. Cotton stalks have been gasified successfully elsewhere and when optimal design and length is found the waste should not cause the experienced problems.

2.2.2.3 Fuel consumption

The specified specific fuel consumption for the SES plant could be achieved during longer operations. The lowest reliable figure obtained was 1.15 kg corn cobs per kWh electricity (net) supplied. This is calculated on bone dry matter.

The fuel consumption during short runs is very high due to the loss during the start-up and stop. This applies to both gasifiers.

The specific fuel consumption of the primary fuel (the agro waste) for the Ankur plant is in the range of the total consumption for the SES plant. On top of this the diesel consumption was (at the same time) approximately 0.3 kg/kWh. It was found that the engine has a high diesel consumption even in full diesel operation, especially on low loads.

2.2.2.4 Pressure drops (losses)

The pressure drops stayed within the given intervals of the SES plant when operating on corn cobs for less than approximately 8 hours. For longer operations the losses gradually increased, especially over the gas producer.

The above applies to the original design. The pressure drop over the installed safety filter increased more rapidly with time

The pressure losses for the Ankur plant (original design) was also very stable until the char bed in gas producer was choked. The choking was found to be caused by too violent vibration, leading to compactation, or when ash was bridging in the chute of the ash outlet. The choking was likely to occur after several days of operation, when the operators learnt how to run the vibrator.

The pressure drop over the original filter was very low (due to the very low separation effect), but when testing a locally made cloth filter, fitted after the original one, the pressure increased rapidly with the water saturation of the cloth.

2.2.2.5 Gas composition

The SES plant showed normal gas compositions when measured. Toward the end of a two shift operation it was obvious that the quality of the gas decreases, causing considerably power loss. After 36 hours of operation (split into three runs) the quality was obviously very poor due to the channelling and high ash content in the reduction bed.

The gas composition actually measured for the Ankur plant showed lower contents of the valuable components than stated by the manufacturer. During operation of a producer gas plant an experienced operator can easily judge the quality of the gas from the power and sound of the plant. As far as the Ankur plant is concerned, this is masked by the poor diesel replacement and regulation.

2.2.2.6 Dust and tar contents

The SES plant operating on a newly filled bed filter and charcoal bed produces a very clean gas (< 7mg/Nm3) and no tar could be condensated at 23°C. The inspection of the inlet manifoid of the engine however shows severe traces of tar and dust from time to time, probably when the bed filter is saturated or when the gas producer is producing dirty gas (poor reduction).

The original filter for the Ankur plant caused thick deposits in the pipes and the inlet manifold. The engine went through a top overhaul (cleaning) after 169 hour of operation at site. Tests on dust and tar contents were not found meaningful before improving the filter.

Three sampling tests were carried out with the original filter and the dust content gradually decreased from 250 to 192 to 10 mg/Nm3. The result can be explained by the gradually decreasing gas flow, which can be verified from the diesel replacement measured at the very same time (dropped from 62 to 26%).

The dust test, when using an additional cloth filter, gave 83 mg/Nm3 at an estimated gas energy rate of 71 kW.

Further systematic tests are needed after the modifications done and after thorough cleaning of all the pipes.

2.2.2.7 Engine oil analyses

Engine oil analyses were carried out for both plants by a company in Harare. The oil analysis gives very valuable continuous information on the condition of the engine, which in this case practically means how contaminated the producer gas is, i.e how efficient the gas cleaning is. One should not forget the ordinary air filter for the engine – the red (African) soil has shortened the lifetime of many engines.

SES

The oil analyses confirmed the gas analysis. Please see Annex I. The evaluation on the gas analysis protocol said "compartment wear appears to be normal" and "iron is slightly high, all other element test results appear normal"

However, as we can see from the oil analysis results in Annex I, the wear has been "extremely high" for some periods. These results coincide with periods when there has been malfunctioning of the filter system resulting in heavy deposits in the engine. The malfunctioning is likely related to the experience of the operators and to the fact that the plant was originally not equipped with any safety filter. There was not either any easy means of detecting the cleanliness of the gas unless opening the pipes.

The plant was initially not equipped with a safety filter. The safety filter which was fitted later on did not function properly.

Ankur

The evaluation of the first oil sample said "check for dirt entry", i.e confirmed what could be visually seen from the inspection of pipes and inlet manifold. The evaluation further said "excess fuel (diesel) dilution", which confirms the earlier described simple regulation system for the speed control. Please see Annex I.

Even after the modifications of the gas cleaning, the evaluations read "wear higher than normal". It is difficult without further analysis of the gas to tell whether the higher wear is originating from soot and tar contaminated gas or from the poor combustion conditions, caused by the complicated procedure required to maintain the correct gas–air–diesel ratio.

This plant originally lacked a safety filter, as well.

2.2.2.8 Condensates, effluent

Condensates

The total amount of the condensates generated has been measured to 35–75% of the fuel moisture. These figures apply to the SES plant, where all the condensate is collected in containers and can easily be drained and measured.

Condensate is collected from the hopper, scrubber, disc filter and a small amount from the bed filter. Smaller amounts also condensate in the pipes/hoses and in the back pressure valve just before the gas mixer. Condensate is also collected from the later on installed safety filter.

Regarding the Ankur plant, the situation is a bit more complicated. The condensate from the venturi scrubber is mixed with the scrubber water and recycled with the water in the sedimentation pond. There has not been any calculation done on the liquid balance over the pond. It is realistic to assume that the amount and type of condensates are similar to the condensates generated in the SES pant. However, the Ankur plant does not generate any tarry, acidic condensate from the gas producer, since there is no condenser on the hopper.

The water in the ponds of the Ankur plant, approximately 1.5 m3, is changed every second week.

Effluent

The liquid effluent from the SES plant are mainly the condensates. The water of the ash pond under the Ankur gas producer contains leaching water. Some water is used, in both plants, for the washing of the filters and gets contaminated with soot and tars.

The composition of the effluent has not been determined. However, experiences from similar types of plants abroad indicates that the condensates contains contaminations that are not, say in Sweden, allowed to be disposed into the sewage system.

A simple evaporation/combustion system has been developed at the project whereby the water is evaporated and the tars burnt. See Annex J.

2.2.3 Operation and maintenance

This section applies to the original design of the SES plant unless otherwise mentioned and is based upon the information given by the project officer, i.e the actual procedures at site towards the end of the third phase. Examples of Daily Operation Reports are attached in Annex N.

Daily

The daily operation require one man available for about 5 minutes every half an hour to every hour, depending on the load and bunker capacity of the fuel hopper.

The start-up period, from ignition of the gas producer to connecting load normally takes 15 minutes.

To ensure good quality of the gas and to keep the pressure drops under 300 mm Wg, i.e to be able to take full load, the charcoal bed is emptied on daily basis. This applies to continuous runs with a length of approximately 5 to up to 16 hours.

The bed, which contains ash and unburnt charcoal, is sieved and 1/2 to 3/4 of the charcoal is reused. The reactor takes 34-35 kg of charcoal to fill after being completely emptied.

The whole procedure, until the engine is running, takes 1.5 hours with two man present, including the check-ups of the engine, batteries and the plant in general.

The fuel is filled into the Ankur plant half that frequent as compared to the SES plant, since the hopper is bigger and the plant is operated in dual fuel. The plant is occasionally operated up for only 50 to 60 hours before the ash chute of the gas producer is clogged. During this period no maintenance is needed of the gas producer. If the operation is forced much beyond this point (and vibrated too violently) the reduction zone can become very compact which requires opening up of the gas producer. To avoid, or rather to delay the opening of the gas producer, the chute is collapsed by poking down through the hopper and reduction zone. The whole procedure until the engine is running in dual fuel mode takes up to 2 hours. This includes removal of ash from the ash pond, cleaning of the filter pond, emptying cyclone from ash, draining condensate from the bed filter and general daily maintenance.

Weekly

When operating in two shifts the gasifier is emptied completely, the disc filter and the swarf filled filter is washed and the scrubber is emptied and refilled with water. Together with the inspection and general cleaning of the whole plant, including preparation (refilling of the gas producer for immediate ignition on Monday morning), the whole procedure takes two men about half a day. This is normally done on Saturdays whereby both plants are serviced in half a day with 2 to 4 men available.

Other intervals

The filter bed is topped up if necessary, otherwise at least topped up with clean shavings every 200 to 250 hours, whereby the dirty lower half is removed and clean shavings added to the upper part. The filter is normally washed with water every second weekend. The top is then left open to let the filter dry out over the weekend.

The condenser of the hopper is cleaned approximately every 250 hours.

The engine oil is changed after 200 - 250 engine hours.

The safety filter cleaned every second week.

Swarf topped up or changed when found brittle, after about 100 - 150 hours of operation.

2.3 OBSERVATIONS, MODIFICATIONS DONE AND FURTHER MODIFICATIONS NEEDED

Out of the three fuels identified for the pilot programme it was established that only the corn cobs are a suitable feedstock for the type of gasifier used. Hence, the results, observations and modifications mentioned in this chapter are generally related to gasification of corn cobs.

As far as the gas cleaning and cooling equipment is concerned, it applies to gas produced from agro wastes for any gas producer fuelling an Otto engine with an output in the range up to 40 - 50 kW when operated on 100% producer gas. The reason to specifying "agro wastes" specifically is, that there is a tendency to higher tar content in the producer gas and for that reason a water scrubber system is included in the gas cleaning train. When operating on wood and charcoal the traditional gas cleaning trains are simpler than considered here, especially for charcoal gasifiers.

2.3.1 SES plant

The design in general is a bit complicated and unnecessarily sophisticated, with many designs details, which gives a very good impression, but results in higher manufacturing cost. The same function could most likely be achieved with a simpler design. Here we refer especially to the gas producer with its double gas outlet boxes, cooling rills, semi-spherical top lid, double mechanical filtering units etc. Some of the parts also takes good workshop facilities for manufacturing.

It should be stressed that the plant delivered was very professionally manufactured and the design gives a very "industrial impression".

For installation and manufacturing in developing countries it is of outmost importance that the design considers the local conditions.

2.3.1.1 Gas producer

The top lid started leaking after a few hundred hours of operation and the design of the groove in the lid for the gasket made it next to impossible to make the gasket (asbestos type rope) stay in the groove when opening the lid. The big diameter of the lid (same as hopper) caused also excessive exposions to the fumes during fuelling.

The lid was modified to a flat disc-type lid using rubber as gasket material and the diameter was reduced by extending the hopper with a conical part. The hopper was also slightly extended to improve the condensing capacity and to increase the bunker volume and thereby extend the intervals between fuelling. The result was positive. Please see photographs in Annex F.

The original perforated metal sheet, forming the inner jacket of the condenser, inside the hopper, was extended by using a 15 mm square wire mesh. This mesh was found to be an improvement, the holes (7 mm) in the original steel plate clogged with tar and fines.

Future modifications; streamline the design of the hopper further. An extension of the cylindrical hopper/condenser likely gives the same cooling effect as all the rills. The hopper is now bolted to the gas producer, by using a big flange and gasket. Experiences with a simple rubber gasket and the hopper standing in a Y-type groove and locked with some simple spring locks are good.

The two gas outlet boxes, of the middle section, give an expensive design and ash is deposited in the boxes. The double outlet likely gives a more even temperature stress in the gas producer, but the same function can be achieved by simply welding the outlet pipes directly to the jacket.

For relatively dry feedstock, like the corn cobs used (10-12% MC), it can be questioned if the heat exchange effect (for drying and preheating the fuel) justifies a double jacketed middle section.

Proposed modification to be tested; Extend the cooling jacket of the top part and make the middle section with only one jacket/wall and place the gas outlets in the slightly extended bottom section.

The bottom part of the gas producer does not contain any grate, with a result that the whole charcoal bed has to be frequently emptied to get the ash out. Besides this tedious inconvenience, channels are formed in the bed after approximately 10 to 12 hours of operation. After about 16 hours of operation the ash is hindering the reduction and emphasized by the channelling, the quality of the gas and the high pressure loss result in very low power output of the engine.

Future modification; A grate, which can be turned by a handle to agitate the charcoal bed for better ash separation and thereby longer maintenance intervals, should be installed.

The design of the ash and inspection lids are generally seen of very good, sturdy design which enables quick and simple handling without using any tools. However, the gaskets show a tendency to leak, which results in partial combustion of gas and thereby high temperatures.

Future modifications; Instead of using asbestos-rope type gasket fitted in a groove in the lids, which have a tendency to be packed with dust and become hard with time, it has been found possible to use waste rubber tubes and flat disc lids. Special attention has to be paid to the temperature, but by extending the length of the flange and by using heat shields and/or insulation on the inside, the temperature can be controlled to allow use of ordinary waste rubber tubes.

The design of the lids and gaskets are stressed, since leaking gaskets are very common in field installations. It is also too common that when a gasket is damaged there is not any new ("European type") gasket available or, if available, it is very expensive because the types of gaskets used are imported.

The gas producer is partly made of high alloy metals which increases the investment cost considerably, even more so if locally manufactured. Only long term tests can verify if the anticipated longer lifetime applies and can justify the additional investment.

2.3.1.2 Gas cleaning and cooling

The gas cleaning train produced very clean gas during the initial stage when the bed filter was filled with wood wool (like the one used for fruit boxes). Please see the test results in Annex O.

The supplementary tests, to determine the cleaning effect of the respective step of the cleaning train was not carried out, but it is believed that the big bed filter served an important role to maintain clean gas. This statement is supported by the fact that, when wood wool was not available, coke and grass was used as bed material, causing heavy deposits in the engine. (This deposit in the engine could be seen in the oil analysis as well).

Towards the end of the third phase it was obvious that the gas, from time to time, was not that clean any longer. The reason is not fully known, but during one of the missions it was learnt that one of the new operators did not fully understand the function of the scrubber and did not maintain the correct water level. It was also believed that the bed was not compacted enough and was thereby saturated within a short period. The leaking hoses also gave higher volume flow through the system and higher dew point. The higher dew point might have hade a negative effect on the cleaning since the condensation has a positive effect on the cleaning.

It was further verified that the amount of soot trapped in the respective step was increased and the dust was trapped at later stages in the train. This can probably be explained by leaking lids of the gas producer. The volume flow increases through dilution with air and since part of the gas is burnt. the calorific value of the gas decreases and the engine calls for more gas, which further increases the volume flow. (This explains the importance of tight lids and gaskets).

Further modifications; The effect of the respective cleaning step should be determined, with the view to eliminate the disc filter and replace the two swarf filled mechanical filters with one cyclone, all to reduce the investment cost. The possibilities to use a venturi type scrubber (see Ankur) should also be seriously looked into, to reduce the investment cost of the scrubber. The reason why these tests (to bypass some steps etc) were not carried out, is likely due to the fact that, towards the end of the project, the accumulation of operation hours was stressed.

Any malfunctioning of the gas cleaning can not be seen unless visually checking inside the pipes, inlet manifold etc. This is not acceptable and a safety filter was recommended /7/ and later on manufactured but not as proposed /8/. The safety filter should choke the engine as soon as excess dust is passing through the cleaning train.

Further modification; An improved combined condensate trap/safety filter placed just before the gas mixer should be manufactured and installed.

2.3.1.3 Engine and generator

There is not much to be said about the generator set, it is of standard type and a well functioning set.

The gas mixer corroded, which is rather due to the gas cleaning (temperature sink before the mixer) and tended to jam. The mixer is very simple to repair, but the next one should perhaps be made a bit sturdier and with better sealed bushings for the valves.

2.3.2 Ankur plant

The Ankur plant is of very simple design and with a minimum of material used. The limit has even been passed for flanges and lids and by using too thin material thicknesses in the throat, lids etc.

The plant was delivered for dual fuel operation (as explained in Chapter 2.2.1). The guidelines for this project was 100% producer gas operation. It can be concluded that the regulation of the gas-air-diesel is insufficient (does not work), resulting in very low diesel replacement. Since dual fuel operation is not part of this project, it is not further discussed in this chapter.

The Ankur plant "came second", somehow, already from the beginning, due to the bits and pieces missing and later on due to the malfunctioning filter and the dual fuel operation. The permanent staff did not have the time nor the energy to fulfil the tests recommended for this plant.

Nevertheless, the Ankur plant contains interesting solutions and, most of all, had a low investment cost. However, it is my feeling that we can not really state its performance, but we do know its shortness and we have identified modifications that certainly would contribute to an improvement of its performance. There is a obvious risk of creating new problems at some other stage if modifying too much (in one step) without testing. It is especially with the latter, where the uncertainties lies.

2.3.2.1 Gas producer

The gas producer is of very simple design and does not contain any (known) high alloy metals, except the steel bars in the grate.

The max capacity of the gas producer could never be tested since the regulation always provided for high diesel injection and thereby limited the amount of gas allowed. When trying to choke the air, to suck in more gas, the rpm goes down, more diesel is injected and the combustion air is not enough. However, it is likely that the capacity of the gas producer is not enough to produce 40 kW electricity on 100% gas, since the diesel "takes over" too easily. The likely reason is that the gas quality is not good enough, especially on higher loads, as verified from tests.

A simple way of establishing this is to run the SES generator set from this gasifier. The reason why this was not tried was that the performance of the Ankur filter unit was so poor that the risk was not taken to spoil the long term tests of the Fiat engine. Another, perhaps the most important factor, was the time available in general and time consumed on the Ankur plant to improve the filter unit.

It has to be mentioned, as well, that the Ankur plant (control panel) was damaged by a storm that tilted a brick wall.

For the future, the capacity of the gas producer and the quality has to be tested as outlined.

The throat ring of the gasifier fell of, probably after gas leaking and overheating. Due to the simple design, it was just a question of fitting a new ring by welding. Long term tests are required for more information.

The fuel and char agitator, the vibrator, agitated the char in the reduction zone too severely causing compacting and clogging. Intermittent operation improved the conditions, but to avoid clogging the char bed and the ash outlet beneath had to be poked.

The specific design of the gas producer makes it difficult to agitate the char bed under operation, besides using the vibrator and poking. The poking does not really serve the purpose during operation and with the risk to poke out the char needed for the reduction.

The ash outlet, through a chute into a water pond, at the same time acting as ash bin, has many advantages, provided the ash could be better separated from the char. The ash in the char bed, together with the compactation, is the reason when high pressure drop occur, and is likely the reason to the lower quality of the gas.

Future modifications; The bars at the bottom of the reduction zone should be replaced by a grate which could be manually agitated (rotated). Not to cause additional possible sources for air leaks, the shaft for rotating the grate should enter the gas producer through the water seal (ash pond). The ash bridging in the chute is believed to simply be a question of changing the angle, i.e the proper slope determined for corn cobs. An adjustable timer for the agitator is preferred, whereby the optimum length and intervals could be found for each fuel.

An interesting observation is that the Ankur plant seems to generate its char consumed for the reduction. However, when 2/3 of the charcoal bed is consumed and replaced by "cob char" the bed becomes blocked. An agitation of the char bed, as proposed, could solve this problem. Realizing that fact that the cob char form a more compact bed (higher pressure drop) than charcoal, the diameter of the reduction zone has likely to be extended on future designs.

2.3.2.2 Gas cleaning equipment

The gas cleaning equipment has been elaborated in earlier chapters. Despite all the shortness and problems faced with this equipment we have to face the fact that the gas cleaning train is compact and simple and thereby cheap to manufacture. The design in general appears very promising for the future.

The performance of the gas cleaning equipment has not been possible to establish in detail, mainly due to the fact that it is difficult to judge what is due to weakness in the design, as such, and what is due to the low performance of the manufacturing and/or installation (i.e. manufacturing is required).

The cyclone was improved by adding a dust collection chamber to the chute under the cyclone. The installation had limited pace for a proper chamber, but though an improvement.

Future recommendations; A standard properly manufactured cyclone with extended dust collection chamber underneath, should be installed. Extension and increased diameter of the gas channel out from the gas producer is recommended to ensure laminar flow into the cyclone.

The water scrubber represents an interesting solution, but again, the manufacturing performance of the venturi pipe and the injector nozzle is so bad that the system can not show its possibilities.

Future recommendations; Have a new one manufactured to be able to test the pressure gained back, water consumption, pump capacity needed and tar and dust separation capacity. The water separation modified accordingly.

The combined filter and water separator mainly acted as a water separator from the beginning. The filter fabric, as installed by the vendor, had a big hole since the fabric did not overlap properly. The plant was operated 50 hours, as instructed, before opened up. During this operation a considerably amount of dust was carried over into the system and the engine. A similar material could not be obtained locally (and no spare one available). After totally 169 hours of operation, on the same fabric but properly fitted, the engine had really heavy deposits and future operation was prohibited until the filtering was improved.

A cloth filter was tried instead of the fabric, but due to the small area (approx. 0.5 m2) and the moisture the pressure drop increased rapidly with the dust collection. A new filter container, with a large filter cloth, was made in a haste for the initial tests. The cleaning effect was improved but the pressure drop was unacceptably high, due to the condensation on the cloth. The problem with the condensation was not solved. Instead the original filter was used as a pre-filer and the cloth filter vessel was turned into a bed filter. The gas quality for this set up is not fully known, but obviously far better than the original set up, as long as the bed is not over-contaminated.

Future modifications; The original filter area is too small and should be extended 5-10 times, to allow reasonable service intervals. The use of tight woven cloth filters is a proven technique but condensation on the cloth must be avoided to keep the pressure loss under reasonable levels.

It has also been noticed that the dimensions of all the piping is unnecessarily small, causing excess pressure losses.

For further information, please see the proposed design.

2.3.2.3 Engine and generator

There is not much more to be added to what has earlier been said. The instrumentation was sparse and the Ankur's Engineer insisted on having an engine room erected, but the compromise was a wall between the engine and the gasification plant, for the control panel.

2.3.3 Effluent and environmental aspects

Both vendors recommended water scrubbers for cleaning of the gas. This is likely due to the fact that tars were expected. It has also been confirmed that the scrubber water, the condensates and the deposits in the systems contains what is generally called "tars" (very complex compounds not fully known).

The contaminated scrubber water and drained condensates is an environmental risk, at the prevailing concentrations, and has to be disposed off accordingly. One possible solution is to dilute the effluent with water to allowable concentrations, which does not seam a sound solution.

This problem was looked into at the project and a very simple method, which is considered quite adequate at this stage, was tested.

A very simple kiln was used for evaporating off the water and burning off the tars. A 10 to 20 litre tin, with open top, was perforated (this type of "stove" is traditionally used for (temporarily) cooking by using charcoal or maize cobs) at the bottom and all around, please see Annex J. This tin is then filled with (anything that burns) rejected charcoal and sweepings (cobs and charcoal), lit and placed on a (old) plough disc. When the fire is going the condensate is poured, a few litres at a time, onto the disc. The charcoal soaks up most of the water, the rest is steamed off and the tar is burnt. The very simple tests indicate that the waste/sweep–ups are enough to burn off the condensates generated, but if not enough, additional waste is easily available. The test further clearly indicated, that more effluent could be burnt per day than the condensates generated by the SES plant during the same time.

For future handling of the waste it is recommended that all the condensates and used scrubber water is first emptied into a bigger container, an oil drum or similar. The drum should be equipped with a tap and a pipe for filling into the "destruction plant". The kiln should be equipped with a outer jacket (cone) to force the steam and evaporated tar to pass through the fire/flare.

This simple method is certainly an improvement with all its shortness and, in my opinion, quite an adequate solution for years to come for rural applications. In urban use, the effluent can be deposited at community refuse dumps.

The soot and ash generated should be berried in a safe pit, preferably covered to minimize maceration, where there is no risk for contamination of water.

2.3.4 Technical viability

The continuity of the records kept does not allow any traditional calculation of the availabilities of the plants. The "human factor" will likely mask the technical shortage and make the evaluation of the records difficult to read.

It can be mentioned, that for a producer gas operated (downdraft pilot charcoal gasifier) sawmill in Tanzania[1] the results of the availability for the tree first years for the sawmill was as follows:

	Total availability: Year 1	Year 2	Year 3
Gasification equipment [a)]	88.7%	88.4%	90.1%
Engine	100%	99.5%	89.0%
Sawmill	99.4%	90.1%	94.4%
Log supply	63.4%	76.5%	97.1%
Test runs, lunches, customs, leaves, waiting for spares etc	76.6%	96.1%	87.7%

Note a): This item includes all the necessary repairs, preparations and start-ups and fuelling, but excludes fuel preparation up to day store.

The results from this pilot project (in Zimbabwe) did certainly not achieve the same very good availability. However, the intension with the above example is just to show that producer gas technique can be technically viable.

Many of the reason for the lower viability for the plants, in Zimbabwe, can likely be explained by the fact that the actual plants were operated on a feedstock which has not yet been tested to the same extent, as for instance charcoal, but it is realistic to believe that after considering the proposed modifications similar records can be obtained and thereby, indirectly, prove the technical viability.

Since the Tanzanian example has been used, I would like to mention that the original (European) gas producer, and parts of the gas cleaning equipment, was replaced by a locally designed and manufactured gas producer, which ran for almost 5,000 hours before the project was closed down for non technical reasons. Furthermore, the engine had by then been overhauled once completely and was due

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[1] Result from the TWICO/SIDA Gasification Project. Utilization of Charcoal Gasifiers for Operation of a Sawmill, a Generator Set and a Land Rover and Efficient Charcoal Production. L. Palm. 1988.
The result covers March 1985 to December 1988. The total engine hours were 2,765 out of 5,918 total working hours.

for another complete overhaul. The trials and errors had certainly caused excessive wear of that engine, as has happened for the Zimbabwean plants.

It can be concluded that the experiences from the operation of the two pilot plants in Zimbabwe (and comparisons with international experiences) have not so far indicated any problem which could not be solved. It is therefore believed, when considering the modifications identified, that it is possible to design and operate a producer gas plant that could show viabilities in the same range as the referred plant.

2.3.5 Service and maintenance

The service and maintenance routines, together with indications on the intervals and duration of the respective routine, have been elaborated in previous chapters.

Due to the character of the project and relatively limited operation hours, together with the shortness in the continuity of the record keeping, the information gathered is not enough for calculation of the service and maintenance costs nor the lifetimes.

However, the observations made are indicating that, if we neglect the initial malfunctions and consider the level of available staff (from time to time) and if we consider the modifications identified, the service and maintenance needed, indicate levels experienced elsewhere.

The same shortness in the record keeping is normally experienced for many projects under similar conditions. This is not a technical issue, but though of outmost importance for the feed-back and for developing and modification of the equipment. This has been considered and guiding the design of the proposed training programme, Annex E.

2.4 RETROFITTING OF DIESEL ENGINES

The FIAT engine used for the SES plant was a retrofitted diesel engine and the experiences from the operation at site are very good.

The only shortness identified, which is not directly related to the engine as such, was the batteries. The same problem seems to be experienced for all the producer gas plants of the same set up; using the engine batteries for starting up the gas producer.

The batteries are heavily loaded during the start-up of the gas producer and during cranking of the engine, especially when the gas quality is not good enough. Due to the heavy use of the batteries their maintenance are of outmost importance. Practically this leads to repeated charging and it is very common that the terminals of the batteries are worn out or broken long before the battery is outaged.

Due to this serious problem it is recommended that the engine is equipped with a small carburettor (and a 1-2 litre petrol tank) for starting on petrol. The carburettor must not be able to take any load. The engine will then supply the power for the start-up fan.

The start-up fan can also be eliminated when starting on petrol, by using an ejector (to the exhaust pipe) to create vacuum in the gasifier.

By starting on petrol (and perhaps stopping on petrol as well) the engine is warm when switching to gas and condensation can thereby be avoided in the engine.

The retrofitting of a diesel engine is varied a bit with the type and brand of engine. It has been experienced that so called pre-chamber engines are not suitable for retrofitting, unless the cylinder head is changed. To day, the most common type of diesel engines are direct injected engines which are relatively easy to convert to an Otto engine. In general, the engine is equipped with an ignition system and the atomizers are replaced by spark plugs. A gas mixer for controlling the air:gas ratio is also to be fitted and if the engine is a prime mover for a generator a speed control is needed. The governor for the diesel pump can usually be modified and linked to the gas mixer for this purpose.

The retrofitting of diesel engines is elaborated in the Sub-contractors final report to UNIDO /12/ and not further elaborated here.

The same report also states the companies in Zimbabwe that could carry out the retrofitting.

2.5 LOCAL MANUFACTURING ASPECTS

A producer gas plant, the gas producer and the gas cleaning/cooling equipment, can normally be manufactured by any workshop which possess a welding machine. Metal cutting, drilling and rolling facilities facilitates the manufacturing, however. Thus, local manufacturing should be quite possible in any country, provided the plant is designed accordingly.

However, the labour skill, i.e the engineering skill from the actual type of plants, may be a limiting factor on the manufacturing of the initial plants.

The most practical, fastest and cheapest approach, seen from a pilot demonstration programme's point of view, is likely to have the initial plants manufactured in an industrialized country and thereafter the initial local manufacturing (of the following plants). The local manufacturing should thereafter build upon the modified design and get a character of copying and adapting to local conditions and availability of material. See Annex E.

The constraints are normally the availability of material, which takes experience when and how modifications can be applied, i.e a design and experience problem rather than a manufacturing problem.

Special attention has to be paid to the requirements on gas tight welding seems and lids, flanges and gaskets.

The observations and modifications identified, elaborated and proposed have to a great extent considered and aimed at a simple design for local manufacturing.

2.6 PROPOSED DESIGN

The proposed design is somehow a mix and match of the two plants and of experience from elsewhere.

The two original plants likely do not contain any component that could be patented nor that have not somehow been tried somewhere else during the history of gasification or within other process industries. The question is to combine the components into a well functioning unit system. It is not known to the author whether exactly the same systems have been manufactured and operated before.

The proposed design, born from the designs, experiences and observations at site, but as well from experiences at other plants, have been considered to an extent. We have to bear in mind, though, that the pilot programme is operating on feedstock which does not constitute the usually used and the experiences are consequently somewhat limited.

A first proposal to a modified design of the gas cleaning/cooling train was presented in the CTA's Third Mission Report to UNIDO /8/, from which some sketches are attached in Annex K.

The specification of the proposed modification is done in the Sub-contractor's Final Report to UNIDO /12/, Chapter 3 and the respective drawings. Relevant drawings from the same report are attached to this report in Annex L, for easy reference.

The design which is proposed in this report consider some smaller amendments and modifications to the design presented in Annex L.

The design presented in Sub-contractor's report /12/, was in general jointly designed and agreed upon by the CTA, the PD and the Sub-contractor during CTA's last mission.

I would like to make reference to the Sub-contractor's statement on page 27 in his report:

> "It is important to realise the full implication of any changes made to the equipment. Changing any one item of a system has corresponding effects on other pieces of the plant in the system. For this reason the benefit of any proposal detailed in this report should be subject to further testing - it would be unwise to produce units based on these proposals without further extensive field trials"

I would like to add; that many man years have been put into development of producer gas plants throughout the world and that engineering and development is an on-going process with design, testing, redesign/modification, further testing and redesign/modification etc. We can just have a glance at the automobile – indeed an on–going process.

Before going into the elaboration of the system, I would finally like to add that the experiences gained at the gasification project in Zimbabwe certainly justifies the inputs and form a very good basis for further activities in this field and thereby, hopefully, eliminates "re–invention of too many new wheels".

In the following we will start from the proposal presented in the Sub–contractor's report. Please see Annex L.

The proposed plant consists of:

- gas producer
- cyclone
- water scrubber
- water separator
- regenerator
- filters
- condensate traps
- gas–air mixer with control
- generator set

We should always keep in mind that almost clean gas can "always" be obtained but on the expense on complicated and expensive plants, which does not become economically viable. Thus, the whole approach is to find simplest design whereby an acceptable performance can be achieved.

The proposed system includes many modifications ("back doors") that the anticipated function is likely to be achievable, provided that the staff, time and funds are available to make the necessary modifications/alternations.

2.6.1 Gas producer

The reduction bed of the SES gas producer showed one severe shortness; the gasifier should be equipped with a manually turnable grate.

The gas producer could be streamlined, see Chapter 2.3.1.1, to simplify manufacturing and reduce manufacturing cost.

For a comparison only, please see a sketch of a simple charcoal gasifier (This is the Tanzanian gas producer, that was mentioned in Chapter 2.3.4), attached in Annex M.

2.6.2 Cyclone

Standard cyclone with the chute ending in an extended (large, dry) ash container.

The efficiency of the cyclone depends on the pressure loss accepted over the same – higher loss, better separation. Since high pressure loss can not be accepted for naturally aspirated engines, the design is finally determined by how well the venturi scrubber can build up a pressure again. Please see Chapter 2.6.3.

2.6.3 Water scrubber

A water scrubber is recommended for three purposes:

- to wash the gas from ash and soot, but mainly tars;
- to cool the gas;
- to re-gain and build up pressure.

A venturi type scrubber fulfils all thee three purposes mentioned above and is extensively used within the industry.

The scrubber water which is recycled, is supplied by a pump, which in turn is powered by a motor from the generator.

2.6.4 Water separator

After the venturi scrubber the gas will be saturated with water and excess scrubber water has to be separated from the gas. This is done in a simple water separator, where most of the dust and tar will be trapped together with the scrubber water. The water separator constitutes the reservoir for the water pump.

So far according to the design in Annex L.

Depending on how much dust is carried over a wet cyclone could be added after the separator. The available pressure is a determinator as well.

It has to be stressed, again, that it might not be the optimum to leave just the very finest particles for the filters. Very fine particles results in a suppression filter (if used) with high pressure drop.

Tests should also be carried out to find out if the dry cyclone could be eliminated. It is quite possible that the scrubber could take all the soot. A wet cyclone after the scrubber, commonly practised in the industry when high degree of separation of very small particles are required, could be more efficient (and cheaper, totally seen) than the dry cyclone and is a highly recommended second step of the mentioned test.

If the scrubber water is found to become too dirty for the water pump and venturi nozzle, a simple gravity sedimentation bed/sand filter could be added, from where the water to the pump is supplied.

2.6.5 Heat exchanger

The gas will be saturated with moist after the scrubber and if a suppression filter is used as the final filter, the gas should be reheated to avoid condensation on the filter cloth (see Chapter 2.6.6) and thereby cause high pressure drop.

Thus, provided the final filter is a suppression filter made of cotton cloth (or similar), it is necessary to reheat, i.e overheat the gas. The overheating should not be higher than just to avoid condensation in the filter. For this purpose a by-pass is used to mix the gas to the wanted temperature.

The heat exchanger (regenerator) is not to be included, if the final filter is of another type, i.e a filter that is not negatively affected by condensates. The condensation is even of an advantage for the dust separation capacity of certain types of filter.

2.6.6 Filters

Main filter (final filter)

After the heat exchanger, or rather the water separator in the proposed case, the gas passes through a filter. The proposed filter is a large bed filter using wood wool as filter material. Please see Annex L. With this set-up, i.e using a bed filter, the heat exchanger should be removed. The heat exchanger will likely cause evaporation of water which else could have been trapped in the bed. The water will then condensate after the filter. The heat exchanger is necessary only for a suppression filter using a filter cloth that absorbs water, as described on previous page. See further below.

The proposed filter is of the same type as the bed filter used in the SES system. The filter has been modified for easy opening and changing of bed material by providing baskets for the bed material and a davit for lifting off the lid and for lifting up the baskets. With two additional bed baskets, always cleaned, filled and readily available, the service time can be made very short. The height of the gas distribution chamber (bottom section of the filter) could be reduced to save material. Alternatively, the depths of the basket increased.

Depending on the availability or cost of the wood wool, other bed materials could be tested, like chopped/crushed coconut husks etc. Elephant grass, corn cobs and coke was tested at the project, but the result was unacceptable for these bed materials together with the original SES gas cleaning train.

Big bed filters are a proven technique and used preferably when cheap bed material is available. The bed filter has a certain capacity to absorb tars. However, the bed filters are voluminous and thereby a bit expensive. The filter should always be followed by a safety filter to prevent carry–over of bed material or to easily indicate any malfunctioning of the gas cleaning. Please see below.

Depending on the local conditions; manufacturing cost, availability and cost of bed material, gas cleaning efficiency of each of the components, pressure drops etc, alternative filter designs should be tested.

Sawdust, but not too fine, is another bed material which has shown good results. However, the proposed bed filter can likely not be filled with sawdust, even even if the gauge of the wire mesh is reduced, since the pressure drop over the filter will likely be too high. A filter with a big area to the gas stream and with less depth is normally used.

One of the proposed filters above should give clean enough gas.

Suppression filters have been extensively used for producer gas plants, especially for downdraft charcoal and wood gasifiers. A gas cleaning train consisting of a cyclone, cooler and a cloth filter (cotton or fibre glass) has appeared to produce a cleanliness of the gas whereby excessive wear of the engine is not anticipated. Due to the tar content of the gas, the proposed cleaning train is extended with a scrubber.

The main filter could alternatively be a suppression filter using a cotton cloth. A well designed filter of this type should give a quality of the gas well in line with the proposed filter and a filter unit with very easy maintenance.

Safety filter

Irrespective of what type of main filter used, the gas cleaning system must always be equipped with a safety filter. The function of the filter is to clog immediately, and thereby choke the engine, if excess dust is carried over, i.e if there is any malfunctioning in the gas cleaning. The condition of the safety filter should be easy to inspect and inspection done on a daily basis, at least.

The filter could be placed next to, before, the gas mixer or right after the main filter.

A design of a simple, proven safety filter is shown in Annex K, Sketch SF-00 and SF-01.

2.6.7 Condenser

The scrubber will, as we mentioned, saturate the gas with water. The dew point of the gas will likely be over the surface temperature (normally equal to the ambient temperature) of the rest of the cleaning train. This means that condensation will occur at some stage. The equipment is designed to make the water (including some tars soluble in water) to condensate as much as possible before the inlet manifold of the engine. The lower the temperature of the gas is, when entering the engine, the higher will the volumetric efficiency be and thereby the power output. Hence, lowest possible temperature of the gas is always preferred, but the lowest temperature should be before the gas mixer.

The condensation itself is affecting the dust separation positively, since the condensation process starts on the dust particles in the gas (and on walls) and the water mist and droplets bind the dust to a size (weight) that can be separated or which can not stay in the gas flow. The very finest particles can be separated hereby.

The recommended design, Annex L, is to use the piping from the filter to the gas mixer as a condenser and equipped with a drainable water trap. It is then important to make sure that the pipes are under shade.

If this is not found enough, or the temperature of the gas before the mixer is much above the ambient temperature, an additional condenser could be installed, like the one shown in Annex K, Sketch AF-00 or AF-01.

The function of this additional condenser is to cool down the gas further (higher volumetric efficiency), to create a temperature sink in the system (to avoid condensation in the inlet manifold) and to further clean the gas.

Since a water pump is available under any conditions, for the venturi scrubber, the condenser could be designed in a way that water is splashed over the condenser and thereby using the evaporation heat for cooling of the producer gas to a temperature lower than what otherwise achieved.

Condensate trap after the mixer

The mixing of gas and air can also create condensation during certain whether conditions, which in practice always happens until the engine is warm and radiating heat onto the mixer.

A combined condensate trap and backfire release is shown in Annex K, Sketch CT--00 and CT-01.

The purpose is to cyclone out water condensating after mixing gas and air and to function as a pressure release when the engine is backfiring. It has been found that the water trapped in this type of device is coloured, i.e further cleaning the gas. The ordinary air filter is another source of dust. The cyclone will also further ensure proper mixing of gas and air.

2.6.8 Gas mixer

A gas mixer similar to the one used on the SES set is the proposed one, but with reinforced bushings to avoid jamming valves.

Another type of gas mixer which gives less pressure drop is presented in Annex K, Sketch GM-00 and GM-01. This is preferred in combination with the described condensate trap (CT-00).

2.6.9 In general

The design is based on using standard components, like standard pipes, flanges, valves etc and by using traditional design on the respective parts of the system.

The dimensions of the pipes and the radius of bends have been designed for optimum pressure drop and use of material.

In general, a "sturdy" design has been guiding the work.

For the disposal of the effluent it is proposed that a simple destruction stove, like we discussed in Chapter 2.2.2.8 is manufactured at site from available scrap.

Finally, the proposed design, with further possible modifications or

alterative solutions, certainly represents an improvement of the two plants which have been used for the pilot programme of which these have made this development possible.

3. ECONOMICAL EVALUATION

3.1 GENERAL REMARKS

I would like to start with a question I have come across so many times; *"Can the rural poor afford a gasification plant?"*

A very kind answer is "no", since the one who is asking has not got the full picture of the investment required for providing power, say for a village. No matter what type of power source used, a heavy initial investment is needed except when there is an electrical grid to be connected to.

The initial question is relevant and constructive if we ask *"Can we afford the additional investment, due to producer gas operation?"*

That is the question we will try to straighten out in this chapter.

Let us elaborate this a bit, since I have come across this question of "comparing apples and pears" frequently. Why are we looking at the cost of heat or power, generated from a producer gas plant? The answer is that there is a foreseeable need of power or heat and somebody has taken a decision to install a production unit and is prepared to pay for its supply/service. That consumer is not interested in how the power has been generated, what he is interested in, is the cost and terms of supply etc. He will look for the available alternative that best suits him. His criteria are very specific to his conditions and the same applies to the financial evaluation he will carry out; the parameters used must apply to the actual condition. In this case the question "can he afford" is very much valid and the financing of the investment and the operation is linked to type of plant chosen.

However, irrespective of how the financing is solved, the ultimate criteria is the cost per unit supplied, sold, consumed etc., though bearing in mind the higher investment cost for a producer gas plant and thereby the higher need of capital initially.

The calculations done in this chapter refer to electric power generation plants of 30 to 40 kW electricity output. The power is produced either from producer gas or from diesel. Dual fuel operation is not considered, since the frame for the project was a 100% producer gas fuelled plant.

As we will find from the elaborations in this chapter, it is basically a matter of answering the question *"Can the saved fuel cost pay back the additional investment cost?"*

We will not consider the difference between financial and economical analysis, i.e foreign currency, shadow factors etc.

3.1.1 Competing options

The tariffs for the national grid is heavily subsidized in many developing countries and very few, if any, power production plants can compete with the tariffs on the national power grid, if normal financial terms are to be applied.

However, the small scale producer gas fuelled power plants considered here, are "never" to be installed where there is access to a reliable power supply from a grid, i.e the subsidized electricity price on the national grid is rather a question of how long can the country afford to subsidize the electricity, especially if the electricity is generated from imported fuels.

As we indicated, an economical evaluation considering shadow–factoring of foreign costs or unskilled labour costs will give another result, but in favour of the gasification plant. For the tentative user/customer it is irrelevant, if part of the costs are originating from foreign currency or not, as long as he can pay in local currency.

Before going into more detailed calculations, the tentative customer must have an indication of what is available technically and an indication of the cost level for the available alternatives. For this purpose, the supplier of the equipment has to provide the tentative users with a generic evaluation. The generic evaluation does not differ between financial and economical costs and thereby which currency originally used for purchasing the equipment.

As a we indicated, power supply from the main grid is not an alternative and consequently, the electricity tariffs are not of interest.

The most realistic alternative to the actual producer gas plants used in this demonstration programme are ordinary diesel generator sets.

3.1.2 Data available

For the generic guidelines presented here, we will use available data form the project and other general information. The accuracy of the evaluation for a particular application can be improved by using site specific data, but the presentation done whereby using feedstock prices and operating hours, gives a good indication of the possibilities or not, at prevailing (and future) diesel prices.

One of the detrimental parameters, which can only be obtained after several years of operation, are the economic lifetimes of the different parts of the equipment. Long term tests/operations can also establish the service and maintenance costs. Since these figures can not be verified in detail from the operation at Nijo we have to consider data available from other similar plants. The experience from the operation of the pilot plants gives an indication of the performance compared to other producer gas operated plants.

The maintenance requirements were elaborated in Chapter 2.2.3.

It was earlier mentioned that the (only) alternative option is a diesel generator set and for this reason, some data for the diesel generator set is needed.

The generator set itself is very much the same, whether it is a diesel generator set or a producer gas fuelled generator set. In the first case the engine is a diesel engine and in the second case an Otto engine or a diesel engine converted to an Otto engine. The generator and the electric control is the same, as well as the skid-mounting.

In general a diesel engine is more expensive than an Otto (petrol) engine. The conversion of the diesel engine is an additional cost, but on the other hand the diesel pump and the injectors can be eliminated. Initially (on the pilot stage) the conversion cost is likely slightly higher than the "savings" from excluding the diesel pump and injection system. However, if this is considered at the purchasing (manufacturing/-assembling) stage of the engine the purchasing cost is about the same[2].

The above means for the generic calculations here, it is accurate enough to assume that the cost of the complete generator set is the same and that only the gas producer and the gas cleaning/cooling train constitute an additional investment for producer gas fuelled sets.

However, we have to consider the derating of the engine when converting to producer gas. For the comparisons possible to work out at this stage, it is quite in order to assume that the total cost of the complete generator set is the same, if we base the calculations on the energy generated. Though we know that a bigger displacement (engine) is needed, when operating on producer gas, to obtain the same electrical output. This simplification is further justified by the fact that an original petrol engine is cheaper than a diesel engine with the same capacity. (A retrofitted

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[2] This statement is commonly used for generic economical evaluations. The CTA has been in contact with Scania in Sweden. Scania has (recently) designed a "gas cylinder head" for its D11 (11 litre) diesel engine. The final, detailed distribution of the costs, for the same engine in gas and diesel mode, could unfortunately not be received in time for this report. However, the company confirmed that the total cost of the two engines are "more or less the same". If the conversion kit is bought separately (as a spare part) the cost is naturally higher.

diesel is not necessarily used for the lower power ranges).

For more accurate calculations, when weighing together derating, correct installed capacity and price difference between diesel and Otto engines, for this particular capacity interval (30 - 40 kW_e), it is realistic to assume that the producer gas engine is about 30% more expensive for the same output.

3.2 FEEDSTOCK PRICE

The price of diesel oil in Harare is Z$ 1.24/ltr (February 1992), which is equivalent to US$ 0.25/ltr.

The "filling station price" of diesel does certainly not apply for rural conditions. The transport/purchasing cost of diesel is normally very high for the actual size of plants. The fuel is transported in drums over long distances. (The author has experienced cases when the price correction factor is 3 to 1 and above, but not yet any case when the factor has been 1 to 1). If the total purchasing cost is worked out as per litre actually consumed by the engine, the cost is likely to be much higher.

The biomass feedstock price vary with transport, handling and needed preparation and alterative use. The approach of this gasification programme is to use wastes for energy generation in rural applications, where the cost of the biomass, the waste, is next to zero. We have for the calculations here considered the cost of the waste itself to nil. As a comparison, the cost of pelletized groundnut shells, sold as fodder (in 1991 outside Harare), is approximately US$ 8 per ton.

The collection and transport can constitute a considerable cost if the, normally bulky, waste has to be collected and transported over longer distances. However, it is in the nature of these small scale power plants (normally less than 50 kW according to /11/, Page 62) that the plant should be placed where the waste is.

The fuel preparation and handling at site requires labour. The cost for the primitive fuel preparation at site (Nijo) amounted to approximately US$ 10 per ton (see Chapter 2.2.2.1). This cost is very high, but many of the various costs for a pilot project are not representative.

The investment cost of storing the waste is considered the same as the investment cost for a diesel store.

For the final calculations three price levels for the biomass waste will be used, namely US $ 0, 10 and 20 per ton.

For an objective comparison it can be concluded that the cost of the biomass is never zero (unless the waste has a negative initial value, which is likely not the case in rural areas) and it is as wrong to calculate with the list price for the diesel.

My personal opinion is that the level of the diesel price (per litre used) is heavily underestimated in most cases.

For the further calculations US$ 0.25 and 0.50 per litre will be used.

3.3 FUEL CONSUMPTION

The fuel consumption, for both types of engines, is calculated for what we found typical load conditions, whereby the fuel consumption is higher than for continuous operations. It is realistic to assume that during field conditions the load conditions are even worse, i.e low loads now and then and frequent starts and stops.

The biomass consumption during typical days (when operating the whole day) was approximately 1.5 kg per kWh electricity generated.

The diesel consumption under similar conditions are normally considerably higher than stated by the manufacturer (for optimal conditions). Typical figures for generator sets of the actual size are 250 - 400 gr/kWh, which applies to 100 and 25% load respectively.

A realistic figure for a comparable (to the biomass feedstock consumption) diesel consumption would be about 325 gr/kWh.

3.4 SERVICE AND MAINTENANCE COST

The service and maintenance cost can not be verified from the activities at the project. The experience from the pilot stage is not either representative for the technique.

For the calculations we have used 4% of the initial investment cost per 1,000 hours of operation. This figure is based upon experience from a number of plants.

3.5 LABOUR COST

A producer gas fuelled plant needs more attendance than a diesel plant.

After the initial training of the operators, we can consider that one man must be available (but not necessarily attending the plant all the time) for a diesel generator set. When operating a generator set on producer gas, we can consider that there must be one additional labourer (all the time) available.

If we try to apply this to the conditions at the project, the salary requirement for the additional (good) labourer would be about Z$ 1,000 per month, or equivalent to US$ 200 per month.

3.6 ECONOMIC LIFETIME AND INTEREST RATE

Lifetime

This is very difficult to establish, since very few demonstration programmes have reached the possible (technical) lifetimes of the equipment, as is the calculation of the economical lifetime, since the experience here is even less.

There are also many non-technical factors determining the life time, which can not be included for a pilot project.

According to Ankur, the lifetime of their plants are expected to 10 - 14 years. None of the plants, known to the author, have been operated that long yet.

The experience from the project can not be explained in terms of figures. However, it is possible to make a judgement of the equipment by comparison with other plants.

Based upon experience from the project in Tanzania and another installation in Kebong Balong, Indonesia (visited during the Study Mission /3/) it is realistic to assume that the lifetime is in the range of 7 years. We have then considered the proposed modifications. Some plants with very long experience were presented at the producer gas course /10/.

Interest rate

To establish a general interest rate might be even more difficult than to establish the lifetime. In many cases the real interest, which is the only one of interest, is negative, so in Zimbabwe.

For the calculations we have used 4% real interest. I would rather call this for "a factor considering the higher initial capital demand for a producer gas plant",than an interest rate.

3.7 INVESTMENT COST

3.7.1 Original plants

3.7.1.1 SES plant

The cost of the original SES gasification plant was approximately US$ 100,000 ex Factory in 1989.

The distribution of the cost is not known, but the price included spares for one year[3] and packing (US$ 6,000 and 3,500 respectively).

This amounts to a total investment cost of approximately 2,500 US$ per kW_e installed. If spares and packing is deducted the equivalent cost is US$ 2,265.

The company have indicated that the cost of the retrofitting is in the range of 10% of the cost of the engine and generator together.

3.7.1.2 Ankur plant

The cost of the original Ankur plant was, the same year, approximately US$ 20,000 ex Factory. The distribution of the cost was approximately as follows:

Engine and generator	62% or	US$ 12,000
Gasification equipment	30% or	US$ 6,000
Control, assembling etc		US$ 2,000
Packing		US$ 2,000

No spares were included.

In addition to this, two pits have been locally built out of bricks. There is one pit under the gas producer and a three chamber pit for the water scrubber. The cost of these pits is not known.

In addition to this the vendor recommended a closed room (house) for the engine, which has not been considered realistic for a plant of this type. The engine room was not built.

If we, for a comparison include an equivalent (to SES) amount of spares and

[3] The spares were generous and not used yet.

a proportional estimation of the cost of the spares, the investment cost per kW_e will be about US$ 550 to 733. We have then calculated with an fictitious output of 30 to 40 kW_e, since it is realistic to assume that the capacity of the gas producer is less than what would be needed for the 40 kw_e genset.

Cost of the gas producer and the gas cleaning equipment

Based upon the figures above and the distribution of the cost items presented by Ankur during the Study Mission, the cost for the gas producer and gas cleaning equipment, including assembling would approximate to about US$ 7,000.

This gasification equipment could probably supply a 30 kW_e generator set only, since it was established at the project that the capacity of the gas producer is certainly not the same as the SES gas producer. This gives us a total cost for the gasification equipment of proximately US$ 235 per installed kW_e.

3.7.2 Proposed plant

The Sub-contractor has worked out a cost estimation based on the SES gas producer and incorporating the proposed modifications, including the modified and redesigned gas cleaning equipment. The gas cleaning equipment follows the original Ankur system, in general.

The Sub-contractor's cost estimate /12/, ex Works price Harare, November 1991, including 10% sales tax is presented below. The tax does not apply for plants exported.

The foreign currency required for the manufacturing, has also been estimated by the Sub-contractor and is presented as "Foreign component" below. This component constitutes part of the respective item cost.

Based on the ruling rate by November 1991 (0.1998 US$ = 1.00 Z$), the equivalent price in US$ is worked for easy comparison.

Please see next page.

Item of Equipment	Price in Z$	in US$	Foreign component in US$
Gas producer	180,500	36,064	3,596
Gas cleaning equipment	69,500	13,886	300
Retrofitted diesel engine	125,000	24,975	13,986
Generator (44 kW) complete with control	45,000	8,991	1,199
Fees and royalty for the gas producer max 5%	9,025	1,802	1,802
Totals	Z$ 429,020	or US$ 85,718	US$ 20,883
Total without royalty	Z$ 420,000	or US$ 83,916	

The total investment cost, excluding royalty, as per installed kW electricity output (40 kW_e) is US$ 2,079.

This is slightly high for a so called locally manufactured gasification plant. Please see the following chapter.

Gas producer and gas cleaning equipment

The cost of the gas producer is US$ 902 per a matching generator set of 40 kW_e output. The equivalent figure for the gas cleaning train is US$ 347.

The total figure for the gasification equipment will then be approximately US$ 1,250 per kW_e.

3.7.3 Comparable plants

The costs vary a lot for the three plants presented in the previous chapters.

After receiving the Sub-contractor's final report, a cost estimation[4] has been done, to get an even more reliable picture of the cost of the proposed design, including the comments in this report. A detailed quotation could not be obtained in time, but the cost estimation is presented below.

We should mention that the engine is the most uncertain component for producer gas fuelled power plants of the actual capacity range. The Sub-contractor also indicates the same in his report /12/. Consequently, the cost estimation from Sweden is based upon an existing, commercial, common type of engine, in this case is an 11 litre engine, which gives approximately 80 kW_e in producer gas mode.

Not to complicate the comparisons and to eliminate scale factors, the cost estimation for the gasification equipment is based on the installed capacity of the proposed plant (40 kW). For the comparisons in Chapter 3.11.1 the investment cost for the gasification equipment is assumed to be 75% higher than the 40 kW equipment (which in fact equals to an alternative cost estimate for a 80 kW gasifier).

The total cost for a complete skid-mounted engine generator set, including control, is approximately US$ 33,000 or approximately US$ 410 per installed kW electricity output.

The generator itself (110 kVA) is approximately US$ 4,100. A 50 kVA generator costs approximately US$ 2,900.

The cost of the gas producer and the gas cleaning train alone totals to approximately US$ 25,000 or about US$ 615 per installed kW.

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[4] Cost estimation done by SwedSteam AB, Stockholm (and Hassels Mekaniska Verkstad, Karlstad and Gotland Gengas, Gotland), Sweden and based on a by Saab-Scania retrofitted standard Scania D11 engine generator set. See further Footnote 2.

3.8 CIVIL WORKS

The cost for the civil work is not included, since this cost is very site specific. On top of that, the simple shed needed for the gasification plant is more or less of the same size as for a diesel generator set.

We are hereby slightly favouring the gasification plant by assuming that the cost for the diesel store and handling amounts to the same as for the biomass store.

This simplification is certainly justified, for the calculations here, by the fact that the normally "wasted" diesel is not considered either.

3.9 OPERATED HOURS PER YEAR AND AVERAGE LOAD

We indicated, initially, that the additional investment for the producer gas equipment is to be paid back by the saved fuel cost.

Practically this means that the number of hours and the actual load, which is not equal to installed capacity, will determine the amount of diesel saved.

Once the plant is installed, the demand will determine the maximum load and hours. However, by planning and good management, the load factor (actuai load to installed capacity) and the hours operated can be optimized.

A generator operated for lightening only (3–5 hours /day) will not operate more than 1,100 – 1,800 hours per year. If the same plant is used for water pumping or workshop activities, another 1,000 hours can easily be added. These figures have been used for the economical evaluation in Chapter 3.11.1.

The effect of operated hours is normally underestimated and the installations should aim at sites where the plant can be used for at least 8 hours per day.

If there is no diesel at all available the situation is different. However, we have not considered availability of fuel (nor the plant availability) in the coming calculations. It is a well known fact that for rural areas, the availability of diesel is many times scarce due to reasons like transport, bad road conditions during rainy seasons, irregular and unreliable supply etc.

During the later part of the third phase, the two plants together were operating at a rate equivalent to about 2,100 annual operating hours. Since the plants had to share the load, the hours for the respective set are summarized.

The load factor was about 55 to 65% during typical runs.

3.10 TRAINING COMPONENT

A producer gas fuelled plant takes more training of the staff at installation. The SES has indicated that 3 weeks of training is necessary after the installation. Ankur gave a figure of 50 hours on traditional fuels and 100 hours on corn cobs.

The figures above probably apply to training of an operator to manage the daily operation and general service and maintenance of the equipment.

If we apply this to the Zimbabwean conditions and calculate with one experienced engineer (operator) for training of two operators during one month, the cost of initial training is approximately US$ 1,000 (Z$ 3000+1500+800). This can be seen as an additional investment cost in the comparison with a diesel engine.

3.11 ECONOMICAL FEASIBILITY OF THE PRODUCER GAS TECHNIQUE

3.11.1 Summary of the various costs and the total cost per unit produced

We have earlier stressed that the question, feasible or not, can not be answered straight forward, since there are so many local and site specific parameters that can not be foreseen. However, the experiences from the pilot project and the elaborations in Chapter 3 will give a good guidance.

A summary of all the costs in the previous chapters is done in the table on next page. The total annual cost and the cost per energy produced is extracted and presented at the bottom of the same table and is reflecting conditions at the project.

The table on next page is based on the conditions at the project and the following:

- Load factor 60%
- Annual operated hours 2,100
- Economical lifetime 7 years as an average for the producer gas plants. 10 years lifetime is calculated for the diesel plant.
- Interest rate 4% (real)
- The capacity of the Ankur plant is reduced to 30 kW as a result of experiences at the project (See Chapter 3.7.1.2)
- Figures in bold apply to conditions similar to the project's experiences.

It must be stressed that the evaluations done strictly apply to the specified conditions only, but valuable tendencies can be drawn from the various costs.

<u>Notes to the table on next page</u>:

*) The figures marked with * refers to a 80 kW plant. See Chapter 3.7.4 and Footnote 4.
The total capital investment for the 80 kW_e plant is estimated from the altenative quotation for the 40 kW_e plant by assuming that the gas cleaning and control equipment is 75% more expensive for the bigger plant. The engine is the same in both cases, i.e for 80 kW_e output.

**) The cost for the diesel engine is based on information from SES and on the Sub-contractor's cost estimation, whereby the retrofitting (according to SES) constitutes to approximately 10% of the total cost of the generator set. This cost has then been reduced from the Sub-contractor's cost estimate for the retrofitted diesel engine and the price further reduced with 30% (no derating, see Chapter 3.1.2). The rest is the same.

Costs:	SYSTEM Diesel 40kW**)	SES 40 kW	Ankur 30 kW	M.-fied 40 kW	Other *)80 kW
Capital investments:					
Engine	15,105			24,975	
Generator	8,991			8,991	
Subtotal	24,096		12,000	33,966	*33,000
Gas producer	-			36,064	
Gas cleaning	-			13,886	
Subtotal	-		6,000	49,950	25,000
Control	2,000		2,000	-	3,000
Total	26,096	90,500	20,000	83,916	61,000
Training	-	1,000	1,000	1,000	1,000
Total capital investments	26,096	91,500	21,000	84,916	*62,000
Annual costs:					
Capital costs	2,988	15,189	3,486	14,096	*13,778
Labour	-	1,000	1,000	1,000	1,000
S&M at 1500	1,566	5,430	1,200	5,035	*4,920
2100	2,192	7,602	1,680	7,049	*6,888
2700	2,818	9,774	2,160	9,063	*8,856
Fuel cost for waste:					
at 0 US$/ton		0	0	0	*0
10 1,500 hrs		540	540	540	*1,080
2,100		756	756	756	*1,512
2,700		972	972	972	*1,944
20 1,500 hrs		1,080	1,080	1,080	*2,160
2,100		1,512	1,512	1,512	*3,024
2,700		1,944	1,944	1,944	*3,888
Fuel cost for diesel					
at 0.25 US$/ltr					
1,500 hrs	3,656				
2,100	5,119				
2,700	6,581				
at 0.50 US$/ltr					
1,500 hrs	7,313				
2,100	10,238				
2,700	13,163				
For 2,100 annual hours: Total annual costs	10,299	24,547	6,922	22,901	*23,178
Cost per US$/kWh produced	0.20	0.49	0.18	0.45	*0.23

3.11.2 Summary and evaluation

We can see from the previous table that **for the conditions we had assumed** (2,100 hrs/year, LF 0.6, waste price 10 US$/ton, diesel US$ 0.25/ltr and all the other parameters) that:

- the Ankur plant gives an energy cost about the same as for a diesel plant. We have then assumed that the present (dual fuel) Ankur plant is operating on 100% gas and derated to 30 kW, to get a more correct investment cost.
- if operating the same Ankur plant in dual fuel mode the cost per energy unit produced will be approximately twice as high as the presented cost.
- the original (on which the calculation is based) Ankur plant has never performed well in the original shape and is therefor not an alternative.
- the energy unit cost for the original SES and the proposed modified plant /12/ is roughly double the energy unit cost for a standard diesel plant, the proposed plant being slightly cheaper.
- the alternative 80 kW plant gives an energy cost which is just slightly higher that for the diesel alternative.
- if the calculation is based on 80 kW engine and generator set and a 40 kW gasification equipment the energy cost would be (US$ 0.34) in-between the proposed plant and the diesel plant.

Thus, it can be concluded that electricity generated by the proposed plant is considerably more expensive than electricity generated by a diesel generator set. Please note again, "under the described conditions".

To get a better picture of the trends for varying fuel costs and operation hours we can study the figure on the next page, whereby the electricity generation cost is shown as function of the annual operated hours for different fuel and feedstock prices.

The graphs are representing the following:

Diesel: The 40 kW diesel plant
Prod gas 1: The proposed plant (according to the Sub-contractor)
Prod gas 2: The 80 kW plant

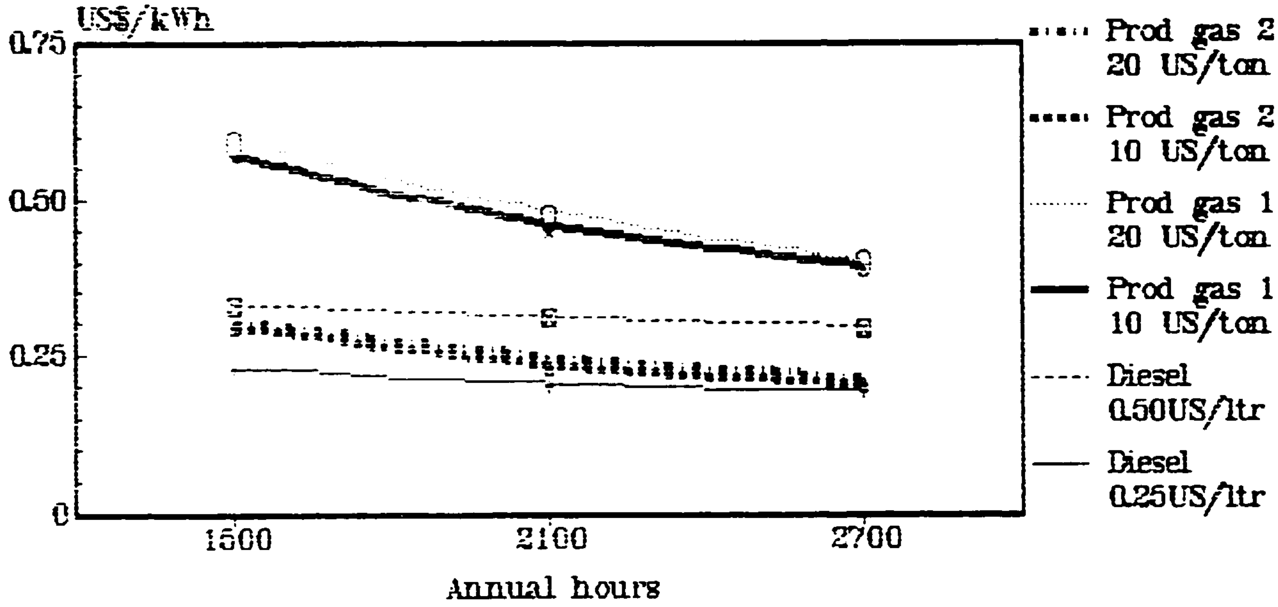
Two price levels have been used for the diesel cost, the filling station price for Harare and one price 100% higher.

Equivalently we have used two prices for the waste, the actual feedstock preparation cost at the project and a 100% higher price.

The power factor is still somewhat low, 0.6, but it based on the conditions at the project during the second half of the third phase. Higher load factors will be of benefit to the producer gas plants.

It can be concluded that the conditions/parameters used are very conservative and trying to reflect real rural conditions, certainly not favouring the biomass alternatives.

ELECTRICITY GENERATION COSTS AS A FUNCTION OF DIFFERENT OPERATION HOURS
– for various fuels and different prices of fuels



Evaluation and summary

The figure clearly indicates that:

- the proposed plant, manufactured in Harare, is likely not economically feasible, at the present price of diesel

- few annual operating hours gives a high energy cost for a plant with high specific investment cost (cost/installed capacity) like the proposed plant

- the bigger producer gas plant, manufactured in Sweden (not considering the freight) shows an energy cost which is just slightly higher than for a diesel plant supplied with diesel to the present (in Harare) "filling station" price

- if the diesel price is increased with more than approximately 50%, the bigger producer gas fuelled plant will likely be more economical at over 2,000 operating hours per year

- these statements are only valid for the assumptions made

Thus, it can be concluded, that the conditions chosen, for what we believe "typical rural installations", and the economical comparisons between the different alternatives clearly indicate that the producer gas technology can become economically viable under certain conditions for rural applications.

The main conditions are that the waste is cheap, not much over US$ 20/ton, and that the diesel price at site, including transport and handling, is over US$ 0.3/litre.

The difference in the initial investment costs, between the proposed plant and the bigger plant (manufactured in Sweden) should be further investigated and experiences transferred to reduce the local manufacturing cost.

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ANNEXES

ANNEX A – SELECTED PROJECT DOCUMENTATIONS

UNIDO UNIDO ONUDI

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

ORGANISATION DES NATIONS UNIES POUR LE DEVELOPPMENT INDUSTRIEL

APPRAISAL MEMORANDUM

Date: 90.05.23

Country: AFRICA REGION - XA/RAF/90/602

Project Title: Demonstration Programme on Use of Indigenous Biomass Resources for Meeting Energy Needs - Phase III

UNDP/UNIDO contribution: US$ 188,500

THE APPRAISAL PROCESS

The project document as submitted to Appraisal needed no modifications in the design format as it was prepared fully in accordance with the established UNIDO guidelines for project dessign, except that the evaluation report of Phase II was not available.

RELEVANCE, FEASIBILITY AND POTENTIAL EFFECTIVENESS

The third phase of this project aims at field testing the pilot gasifiers installed during the second phase. This mainly involves the operation of the gasifiers with different feedstocks in order to determine the "best practice" operation and maintenance parameters. It will result in the preparation of a report containing all the technical characteristics to be used, inter alia, in the training programme to be organized for operation and maintenance personnel from other PTA countries.

In view of the fact that no evaluation report of the previous phase was made available, it is difficult to assess whether the outputs of the second phase were actually produced and whether that project had achieved its stated objectives. However, as pointed out in the project document

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Action: NS 24/5

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PART A CONTEXT

1. The Energy Sector

The Preferential Trade Area for Eastern and Southern African States (PTA) has abundant energy resources, such as woodfuel, coal, petroleum, and hydro-electric potential which is unevenly distributed among the Member States. Fuelwood is the most important source of energy as it provides about 70 - 80 per cent of the total energy consumption in the subregion. Annual consumption of fuelwood is estimated at about 200 million cubic metres.

Of the 17 member countries of the PTA, all but five are producers of hydro-electricity, the five countries being Botswana, Djibouti, Lesotho, Seychelles and Somalia. Hydro-electric potential is estimated at about 106,000 MW. The countries are capable of producing an average amount of nearly 600 billion KWh per annum. The current installed capacity of hydro-electricity in the subregion is only about 5,400 MW, a mere 6 per cent of the overall potential. According to a survey carried out by the Economic Commission for Africa (ECA), planned capacity during the 10 year period of 1988-1998 has been estimated at 18,600 MW. It has been estimated also that approximately 72 per cent of the total current installed hydro-electric capacity is in Zambia, Zimbabwe and Mozambique, primarily in the Kariba Dam complex, the Cabora Bassa and Kafue facilities.

In the area of petroleum energy, all but one of the countries (Angola) are net petroleum importers. Exploration of oil is an ongoing activity in countries, such as Ethiopia, Kenya, Mozambique, Somalia, Tanzania and Zambia. However, no major discovery has been made. The subregion has a total of ten refineries with installed capacity of a little over 12,000,000 metric tons. Most of the refineries are outdated and are characterized by frequent breakdowns of plants and machinery, and as a result, they are running well below installed capacity.

The subregion also has large deposits of coal, notably in Botswana, Mozambique, Angola, Malawi, Swaziland, Tanzania, Zambia and Zimbabwe. Total proven reserves are about 12.4 billion tons of bituminous coal, 1 billion tons of sub-bituminous coal/lignite and 2 billion tons of peat. However, the transformation of these for commercial energy consumption is constrained by, inter alia, inadequate infrastructural facilities, high investment costs, and lack of any coherent strategy for the development and utilization of coal.

Since 1980, emphasis is being put on the need to develop biomass and solar energy. The level of R&D in this sector is still inadequate and most of the technology developed, including plant and equipment, for energy production are imported from the developed countries. Some countries, such as Ethiopia, Kenya and Zimbabwe, are stepping up their development programme in the area of new and renewable sources of energy.

2. Regional/national strategies, objectives and priorities

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 alternative, new and renewable sources of energy at the national, subregional and regional levels.

The PTA recognizes that there is a need for regional/subregional co-operation for promoting the development and utilization of biomass as an effective source of energy. The Council of Ministers (PTA), in adopting the Energy Plan of Action of the PTA in December 1987, called on the Member States to encourage:

(a) Research and development in new and renewable sources of energy and specifically requested the international community to assist the PTA countries in the development and testing of pilot demonstration projects, particularly for biomass;

(b) The exchange of information/data and techno-economic results of pilot-scale subregional co-operation in energy production;

Africa's Priority Programme for Economic Recovery and Development (1986-1990), adopted by the Assembly of Heads of State of the Organization of African Unity (OAU) in July 1985, also re-iterates that "greater co-operation should be fostered among Member States in the subregions and region through harmonized policies, joint exploitation and development of energy technologies, equipment and training programmes."

3. Prior and Ongoing Assistance

In 1985, UNIDO, under the programme for the Industrial Development Decade for Africa, through a project RP/RAF/85/627, funded a pre-feasibility study to examine the technical and socio-economic viability of generating energy for rural use by means of the gasification of agricultural residues with a view to establishing a pilot programme, should the study prove the concept practicable. It was expected that the pilot programme would provide a sound data base for the application of this source of energy in the PTA subregion. Prior to undertaking the study, preliminary investigations were carried out and on the basis of the information and statistics made available for the study, Zimbabwe was selected as the host country for the pilot plant.

Phase II of the project, XA/RAF/88/681, involved, inter-alia, the installation of a pilot gasification plant which included gasifiers, modified engine generators and ancilliary equipment.

4. Institutional Framework for Industrial/Energy Development

In the PTA countries, the Governments are responsible for formulating energy policies and programmes. Apart from the Ministries of Energy, which are the legal agents for energy planning, development and utilization, there are a number of public corporations responsible for the development of energy resources, and, in some cases, ad-hoc organizations have been set up to look into the development of new and renewable energy resources for rural needs in particular.

Regional institutions, such as the African Regional Centre for Engineering Design and Manufacturing (ARCEDEM) and the African Regional Centre fro Technology (ARCT), are also promoting technological development in the energy sector.

PART B PROJECT JUSTIFICATION

1. Problems to be Addressed: The Present Situation

Energy consumption is a major indicator of socio-economic development. Energy in various forms is a vital input to almost all human activities ranging from cooking, lighting, heating, agricultural production, manufacturing and transportation. The provision of adequate supply of energy is therefore essential to national development. The unequal endowment of energy resources among the countries in the PTA subregion coupled with the gap in energy technology development provide a unique opportunity for subregional co-operation. At the moment, all the PTA countries, except Angola, import their oil requirements. It has been estimated that, for some countries, as much as 40 - 50 per cent of foreign exchange earnings are spent on oil imports. Over the years, limits in the availability of energy resources, technological change, location, prices and use of certain fuels have necessitated the search for new energy alternatives in Africa.

In the rural areas, where access to central power production is limited, development of technologies utilizing locally available agricultural waste is a necessity. In such areas, there is an increasing dependence on diesel powered auto generators for decentralized power generation needed for agricultural (irrigation, primary processing, etc.) ar household uses. The effective utilization of these potential resources for energy could contribute immensely to achieving self-reliance in energy and to minimizing some of the problems associated with woodfuel consumption and deforestation.

The development of new and renewable sources of energy is a practical option of the PTA countries, particularly for decentralized small-scale energy supplies. This sub-sector covers solar, wind and biomass. In the areas of biomass technology, several ad-hoc studies have been made and there are a few small-scale projects for the conversion of molasses into ethanol in Kenya, Mauritius, Malawi and Zimbabwe.

Given the large quantitites of raw materials available for biomass production in the subregion, the Council of PTA Ministers, at a its meeting held in Kampala, Uganda, in December 1987, endorsed the recommendations of the Committee on Industrial Co-operation, namely that PTA Member States should intensify their efforts in R & D activities, testing and in establishing pilot demonstration projects for biomass production. This is a realistic approach to alleviate some of the problems of energy. In the subregion, most PTA countries do not have domestic resources of hydro-carbon fuels and have large rural communities located far away from the electricity distribution grid. The subregion, however, produces a variety of crops, the agricultural wastes of which could be converted into energy. Such crops include barley, beans, coffee, corn, maize, cotton, groundnut, sugar cane and wheat.

Zimbabwe has a wide variety of the major crops used in biomass production. The country has adequate infrastructure, including a well developed electricity distribution grid. Like other PTA Member States, the country has a large percentage of its population in the rural areas and the rural communities need energy to support agricultural and small industry activities. The major rural energy consumers are farmers who need to irrigate the farming fields and undertake preliminary processing of their harvest. Energy consumed is mainly diesel oil which is used to fire diesel engines and generators and also boilers for steam production.

Agricultural production is carried out by small holders, privately owned commercial farms and large state farms owned and operated by the Agricultural and Rural Development Authority (ARDA). The marketing of crops is done by and through the Grain Marketing Board (GMB). Agricultural crops are delivered to GMB depots where, as in the case of groundnut, they are shelled or, as in the case of corn and coffee, they are partially processed, removing husks and parchment. It is estimated that the country produces approximately 640,000 tons of corn, 12,000 tons of groundnut and 10,000 tons of coffee. This therefore means that the country has an adequate supply of agricultural residues selected for the pilot programme, namely coffee, husks, groundnut shells and corn-cobs. These agricultural wastes are easily collected in the central depot of GMB and ARDA. The amounts of waste readily available for pilot phase are 160 tons of corn cobs, 960 tons of coffee husks from the Banket depot of GMB, and 600 tons of groundnut shells from the Cleveland Dam depot of GMB (see pre-feasibility study).

Zimbabwe has some capabilities in biomass gasification technology. A source of commercial gasification experience is the NEI Cochrane Engineering (pvt) Ltd., in Harare. This company has devised and sold a number of coke and anthracite gasifiers for rural use. It also markets wood/charcoal, gasifiers with producer gas cleaner systems. Nevertheless, a biomass gasifier capable of processing the three selected agricultural residues has not been developed. NEI Cochrane Engineering and other corporations in Zimbabwe have equipment fabricating capabilities and facilities. NEI Cochrane has, in fact, expressed interest in participating in the development of a small agricultural waste gasifier utilizing, in particular, maize cob. The company is interested in the supply of equipment and in making available local experts to train equipment users. It should be mentioned that this company has adequate fabricating facilities.

The pre-feasibility study for a gasification plant based on agricultural waste was done by UNIDO. A detailed analysis was carried out of the structure of the agri ultural system, means of disposal of agricultural wastes, physical/chemical properties, analysis of the agricultural residues to be used as feedstock for gasifiers, etc. (see copy of pre-feasibility report). A pilot unit was found necessary for on-line exploration of the viability of converting agricultural wastes to mechanical and/or electric energy. It was noted that the agricultural wastes available with suitable technical and economic characteristics for use as gasifier feeds were corn-cobs, coffee husks/parchment and groundnut shells. For flexibility to supply a range of demands using a unit of only one size, for reliability of rural service and ability to operate as high on overall efficiency as practicale, a modular system with a capacity of 50 KWh net electricity output was also proposed. The preferred location of the pilot programme was the Nijo Estates which by itself produces 1600 tons of corn per annum (approximately 160 tons of cobs) and consumes an average of 38 KWh/per hour all year round.. The estate being only 30 km from Harare has a convenient access to spare parts, consumables, and transport systems.

Through project XA/RAF/88/681 - Demonstration programme on the use of indigenous biomass resources for meeting energy needs Phase II - two gasifiers were installed. The gasification technique is to be used to convert agricultural residual wastes (corn-cobs, groundnut shell and coffee husks) into useful forms of energy. This technique involves the partial combustion of solid feedstock to produce a combustible gas which, after appropriate filtering and cleansing, can be used directly in an engine/generator and/or engine/pumps. This particular process is appropriate, because the feedstock is available at relatively low or zero costs. Ideally, the pilot programme facility should have access to selected farm waste. With this technology, the design of equipment for gasification units is not very complicated and some aspects of the equipment were fabricated locally. In addition, this technology is considered could be appropriate, because of the relatively low capital cost involved and the level of skills required for operation and maintenance of the plant.

Although the gasifiers have been fully installed, there is a need to initiate intensive technical operation and testing of the gasifiers with a view to:

(a) indicating the operational and/or new design modification, if necessary, for operation with different feedstock available in the subregion; and determining long-term operating characteristics under prevailing conditions;

(b) train a cadre of local technicians in the operation and maintenance of the gasifiers so that they, in turn, will train others, when the gasifiers find wide-spread application;

(c) Undertake a survery/evaluation of the gasifiers to determine the viability of the gasifiers in the subregion and assist the Governments in developing programmes for the local manufacture of the gasifiers and rural application of the energy generated.

2. Expected End of Project Situation

(i) The project will provide a basis of ongoing technical co-operation among the countries in the PTA subregion in that the techno-economic viability of the gasifiers will be validated in these countries.

(ii) The documentation on the design of the gasifier, including any modification to be made will be disseminated to other interested Member States with a view to encouraging further the local manufacture and use of these gasifiers.

(iii) As already indicated, there is an increasing dependence on diesel-powered auto generators for decentralized power generation needed for agricultural and household uses. However, given the foreign exchange constraints in most of these countries, the development and wide-spread use of the gasifiers in the rural sector will constribute to

- conserving foreign exchange spent on imported fuel; and
- achieving a certain degree of self-reliance in energy.

3. Target Beneficiaries

Through this project, Nijo Estates, where the pilot programme is located, will be the direct beneficiary of technical assistance provided by UNIDO which will enable it to use more efficiently the agricultural wastes for energy production.

The demonstration programme will also cover other crop processing estates in rural Zimbabwe. The pilot gasification technology will also be demonstrated for participants from other PTA member countries and popularized in the rural areas of the subregion.

4. Project Strategy and Institutional Arrangements

The project will be implemented through the Ministry of Energy, Water Resources and Development in co-operation with Nijo Estate/AROA. The pilot demonstration/tests will also be carried out for participants from other PTA countries and the test results will be made available to them through the Ministry of Energy.

The technical report on the pilot demonstration gasifier programme will be utilized by other interested Member States in the subregion for promotional activities in their respective countries.

The project will be backstopped by IPCT/TP/BT. The respective roles of the international experts and the experts of the consulting firms will be determined by UNIDO after mutual discussions and agreement at the initial stage of project implementation with regard to each of the project outputs.

5. Reason for UNIDO's assistance

Phase I and Phase II of this project were financed and executed by UNIDO. The launching of Phase III would involve some foreign exchange resources which have not been budgeted for by the Government in their development budget. UNIDO's assistance in the project will mainly be in the form of mobilizing internationally available experience and expertise in the subject of gasification, identifying commercial manufacturers and research and development centres with accumulated technical know-how and appropriate prototype equipment, utilizing experiences gained in other international pilot projects and training programmes and for co-ordinating the project with other ongoing activities. UNIDO will also play a crucial role in utilizing the pilot programme results to promote commercial manufacture of the gasifiers for rural use in the subregion.

6. Special Considerations

The countries of the PTA subregion rely on the use of woodfuels for cooking, heating and lighting. The rapid depletion of forest reserves and the recent drought which diminished the subregion's agricultural output and threatened its ability to feed its population, have raised doubts on the rationale of utilizing woodfuel and strengthened the need to develop other sources of energy. The development of new and renewable sources of energy is a major and practical option for the countries of the subregion and is in line with the Nairobi Plan of Action on the development and utilization of new and renewable sources of energy.

The project also aims at promoting technical co-operation among developing countries, TCDC, in that technical knowledge/experience gained will be tested and be applicable elsewhere in the subregion, perhaps with different feedstocks.

7. Co-ordination Agrrangements

The project will establish links with other projects on rural energy development (utilizing agricultural waste/wood waste from sawmills) in the subregion. Information and data compiled by experts of these projects could be useful as background information for the international expert and expert consulting firm who are expected to undertake field trials and a market survey under this project.

8. Counterpart Support Capacity

The Government of Zimbabwe/Ministry of Energy, Water Resources and Development, in co-operation with ARDA/Nijo Estates, will provide the sheds for the gasifier pilot plant and aid work services. The Nijo Estate is also capable of producing adequate agricultural waste as raw material inputs for the gasifiers.

C. DEVELOPMENT OBJECTIVE

The development objective is to achieve increased self-sufficiency in energy supply, particularly in the rural sector, thereby reducing the PTA subregion's dependence on imported fuel and conserving foreign exchange.

D. IMMEDIATE OBJECTIVES, OUTPUTS AND ACTIVITIES

1. 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.

2. 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.

OUTPUTS

Output 1 A fully operational demonstration gasification programme in the PTA subregion (gasifiers were installed during phase II of the project)

	Activities	Start (month)	Duration (months)
1.1	Assignment of experts to carry out the under-mentioned project activities	1	1
1.2	Preparation of sub-contract for local engineering company to	1	1

	Activities	Start (month)	Duration (months)
	assist project personnel in conducting tests (e.g. gas analysis) and to modify existing gasifier design to suit local conditions		
1.3	Organization of testing programme including planning of fuel collection, transportation, treatment and storage; pattern of data collection and methodology of analysis to be done	2	2
1.4	Implementation of testing programme; this involves running of gasifiers with the different feedstocks, analyzing the gas output mainly for tar contents, modifying feed preparation and/or gasifier to reduce tar content, conducting long-term operation with full load to record operating characteristics and developing "best practice" operation and maintenance procedures	4	continuous
1.5	Development of design modifications	6	10
1.6	Train local personnel in the operation and maintenace of the technology	2	continous

Output 2

A report containing description of the design and fabrication of the gasification technology, the characteristics of operation of the gasifiers indicating the design modifications necessary for optimal functionning with the different agricultural resources/feedstock; economic analysis/data of the field trial of the technology.

	Activities	Start (month)	Duration (months)
2.1	Assignment of experts, preparation of framework to carry out project activities	1	1
2.2.	Compile information on design/fabrication and modification of the gasifier technology, the production process and any other variation developed during the project life	4	continous

	Activities	Start (month)	Duration (months)
2.3	Collect and analyse data and prepare techno-economic analysis on the design/fabrication or modification process and field trials of the technology	4	12
2.4	Investigate the viability of the technology in other Member States, particularly in the rural areas	6	6
2.5	Prepare detailed report containing all the technical characteristics; economic analysis and viability of the technology, including recommendations for future modifications	10	6

Output 3

A report on marketing survey and potential for the local manufacture of gasifiers in the subregion.

	Activities	Start (month)	Duration (months)
3.1	Assignment of experts to carry out project activities for the realisation of output 3	6	1
3.2	Consultations and discussions of technology with engineering consulting company/contractor; review and analyse data on technology, including design and use of feedstock	8	1
3.3	Collect and analyse other relevant data	8	2
3.4	Investigate the market for energy products by gasifiers	6	2
3.5	Consult with potential entrepreneurs/engineering firms to determine potential for local manufacture of gasifiers	14	2
3.6	Prepare report on marketing survey and potential for further investment in the gasifier technology	14	4

Output 4

A core of eleven operation and maintenance personnel trained in all aspects of gasifier operation, monitoring, engine maintenance, fuel preparation, load connection and mangement of overall operations.

	Activities	Start (month)	Duration (months)
4.1	Assignment of same experts/ contractor as for output 1 and short-term consultant to conduct local on-the-job training	1	2
4.2	Design of training programme based on level of personnel and experiences during design and modifications and field trials of technology	2	continuous
4.3.	Implement/conduct training programmes and group training for participants from other countries	3	continuous

INPUTS

I. Government Inputs

At the end of phase II of the project, the national counterparts, Department of Energy of the Ministry of Energy, Water Resources and Development (DOE) and the Agricultural Rural Development Authority (ARDA), have, in principle, agreed on providing the following inputs:

(i) Facilities

Physical structures will be provided to house the installed plants (these have already been almost completed), a shed will be built for fuel storage, office space is being prepared at the site for project staff.

(ii) Personnel

ARDA will provide four artisans, including an engine mechanic and an electrician as trainees, as well as a project co-ordinator, and one labourer from the estate will be assigned to the project. DOE will provide one trainee and the project manager. These assignments will be for the duration of the project. The Government will also identify candidates for the post of a project director and a statistician.

(iii) Services

ARDA and DOE will jointly provide transportation and organizational services, as necess[illegible] collection, delivery and storage of the variou[illegible], to be used in the testing programme. Unskilled labo[illegible] also be provided.

II. UNIDO Inputs

BL	Item	m/m	US$
11-00	Expert in gasification technology (CTA); split missions as follows: month 1 - 3 month 7 - 8 month 15 - 16	7	63,000
	Short-term experts for the preparation of the testing programme and training of operators and market survey	1.25	12,000
15-00	Project travel (statistician)		4,000
16-00	Staff travel: 2 missions to Harare of one week duration each, one during month 2 for planning of testing programme, organization of all inputs and training of operators		8,500
17-00	National expert (project director)	16	24,000
	National expert (statistician/ marketing expert)	6	9,000
21-00	Subcontract with local engineering firm for provision of services, as necessary, during testing; for harvester modification to enable easier collection of corn-cobs; and design modifications of gasifier for fuel and local manufacturing conditions	6	30,000
32-00	Group training programme (Study tour)		5,000
	(i) Round trip air ticket for five at an avarage of US$300		1,500
	(ii) Per diems for five participants for 7 days at US$100		3,500
41-00	Expendable equipment (e.g. engine oil, diesel, cables and other hardware, baskets, hand tools, protective clothes, water, filter and cleaning material, fuel for transport, etc.). This is deemed necessary for continuous operation of the pilot programme in case there is some delay in Government input delivery		10,000

BL	Item	m/m	US$
42-00	Non-expendable equipment (computer/printer, low voltage starter, power cable, electrical components, spare parts)		20,000
51-00	Miscellaneous		3,000
99-00	TOTAL		188,500

E. RISK

The success of the test runs to be carried out under this project depends on the continuous supply of agricultural waste and other consumables for the operation of the gasification technology. Failure to provide these could disrupt the implementation of the project.

The likelihood of this occuring is minimal, as the Government has made provision for the supply of a minimum of 49 tons of corn cobs, etc.

F. PRIOR OBLIGATIONS AND PREREQUISITES

The Government of Zimbabwe should identify the counterpart staff to be assigned to the project and will inform UNIDO of the names of the counterpart staff piror to the assignement of the international expert. The project document will be signed by UNIDO and UNIDO's assistance to the project will be provided only, if the prior obligations stipulated above have been met to UNIDO's satisfaction.

G. REPORTING, EVALUATION AND FOLLOW-UP ACTIVITIES

The project shall be subject to evaluation in accordance with the policies and procedures established for this purpose by UNIDO. Upon successful completion of the project, UNIDO will review the reports to determine further technical assistance needs for the local manufacture of the gasifiers in the subregion.

H. BUDGETS

The project budget sheets are attached.

ANNEX B – CTA's JOB DESCRIPTION

Annex II

JOB DESCRIPTION

Post title:	Expert in gasification technology
Duration:	7 months split mission
Date required:	June/July 1990
Duty station:	Harare, Zimbabwe, with possible travel to other neighbouring PTA countries
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 expert will be responsible for the organization and implementation of the testing programme of the installed pilot plants.

In particular, he will:

1. Prepare a detailed programme for testing the installed plants, including planning for collecting agricultural residues as fuel; specification of parametres to be monitored; methodology for data collection; testing schedule; etc.

2. Prepare guidelines for the operation of the gasifiers;

3. Prepare guidelines for performance analysis;

4. Supervise and assist in conducting test runs of the gasifiers with the different feedstocks;

5. Liaise with subcontractor (local engineering firm) on the development of design modification;

6. Together with the statistician and short-term consultant on marketing, review and analyse data on the gasifier technology and the market situation for energy products by gasifiers;

7. Design and conduct training programmes for technical operators;

8. Prepare, in collaboration with the other experts and local engineering firm, a detailed report containing all the technical characteristics, economic analysis and viability of the technology, including recommendations for future modification;

9. Organize and implement a group training programme/demonstration programme on the gasifier technology;

10. Prepare a quarterly report and terminal report on the project implementation.

Qualifications: An Engineering Degree or equivalent with experience in pyrolite gasification.

Language requirements: English

ANNEX C - PROJECT DIRECTOR's JOB DESCRIPTION

JOB DESCRIPTION

Post title: National expert (project director)

Duration: 16 months

Date required: June/July 1990

Duty station: Harare, Zimbabwe, with possible travel to other neighbouring PTA countries

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:

1. As national project director, the expert will be responsible for mobilizing all local inputs for the testing programme and identify and select the local crew to carry out the full programme;

2. He will assist the international expert in gasification technology in the organization and implementation of the testing programme on the installed pilot plants;

In particular he will:

(i) Supervise the running of the gasifiers with different feedstock analysing the gas output, modifying feed preparation and/or gasifier based on the analysis;

(ii) Compile information on the design/ fabrication and modification of the gasifier technology, the production process and any other variation developed during the project life;

(iii) Together with the other expert, prepare a report on the technical characteristics of the programme and make recommendations for future improvements.

Qualifications: Degree in agricultural engineering with experience in the operation of pyrolite gasification technology

Language requirements: English

ANNEX D - STATISTICIAN's JOB DESCRIPTION

DESCRIPTION OF DUTIES FOR THE STATISTICIAN FOR THE DEMONSTRATION PROGRAMME ON THE USE OF INDIGENOUS BIOMASS RESOURCES FOR MEETING ENERGY NEEDS: PROJECT XA/RAF/90/602

Post title: National Expert (statistician/marketing expert)

Duration: 6 man-months, subject to conditions of Agreement

Date required: January 1, 1991

Duty Station: Harare, Zimbabwe

Purpose of Project:

To validate the feasibility of the pilot gasification technology to convert agricultural waste into energy with a view to promoting its widespread utilisation throughout the PTA subregion.

DUTIES

A. Overall survey of agricultural wastes and related issues in PTA countries.

B. Detailed survey of agricultural wastes and related issues in Zimbabwe.

The following topics/issues will be considered in the survey:

1. The agricultural wastes that have been identified in the Demonstration Programme are:

   maize cobs;
   groundnut shells;
   coffee husk;
   appropriate alternative wastes may be suggested.

2. Quantities of available wastes and seasonality:

3. Methods of production and handling:

   agricultural practices affecting the production of agricultural wastes;

4. Geographical distribution:

5. Settlement patterns:

   as they affect production and use of agricultural wastes, including main types of settlement, typical activities and development trends;

6. Alternative uses of the wastes:

   related to the geographical and settlement patterns, substitution costs, socio cultural factors etc.

7. Preparation of the waste to meet gasification requirements:

physical requirements, transport and storage needs;

8. Power distribution patterns:

main grid;
present location and use of diesel powered units and other power sources;

9. Future trends;

10. Other relevant data;

11. Identification of potential sites for gasification;

demand for power and characteristics of the demand;
availability and nature of existing power;
socio-economic aspects (briefly);
viability of gasification, availability of revenue;
financing and infrastructure;
potential for further investment in gasifier technology;
possible way(s) of introducing the new technology.

ANNEX E - TRAINING PROGRAMME

TRAINING PROGRAMME

The producer gas technique is new to most of the developing countries and normally aiming at installation and operation in rural areas where the level of education and training can be expected to be lower than for the country in general. Technical assistance may also not be available. All together, this further stresses the importance of genuine training.

The milestones of the training conducted at the project, mainly during the third phase, together with the experience gained, has guided the following frames for a training programme to be adopted or form guidelines for similar activities implemented in the future.

The guidelines below are based upon the actual level of the staff available for this project (phase three), but experience from similar activities in other developing countries have influenced, as well.

1. Initial training

All staff, preferably including additional staff to compensate for drop-out:

- Introduction of the technique, purpose of the project, what we want to achieve, how and when.
- Explanation of the function of the plant and the respective component in brief, if possible both theoretically and practically.
- Give the staff an opportunity to actively take part in the installation and commissioning. Normally the manufacturer, or qualified experts will then be present.
- Presentation and going through the manufacturer's instructions and manuals on site.
- Risks and hazards with producer gas plants – precautions.
- Check-up of reception and understanding.

All the above mentioned gives valuable information for the following training and for recruitment and delegation of responsibilities.

Besides the installation, the pre-initial training should be given a minimum of one week.

The organization of the staff should be clear by now, especially in terms of responsibilities, to assure adequate future training and of "right man".

The following section applies to all staff as well. It should be stressed also, that the managers must fully understand the function and practical operation of the plant.

- Initial operation of the plant under qualified supervision.

- Stating responsibilities and obligations regarding the actual, practical and daily work.

- Presentations and going through safety regulations/instructions.

- Following of the manufacturer's instructions and manuals and working out log books. Find practical routines for keeping the log books.

- Carry out a complete service of the plant (i.e all maintenance mentioned in the manuals, except overhauls of the engine).

2. Service and maintenance

Introductory course

This section applies to all operators and relevant parts to include managers as well and should be carried out by experienced and qualified people at a very early stage of the project, but when the staff is somewhat familiar with the equipment. (The first oil change could be a guidance.)

Maintenance can never be stressed enough. Consequently, all the activities should be stopped and all the managers be actively involved to really emphasize the importance.

- What is maintenance and why maintenance?
  To be explained by local staff in a "local language".

- Exemplify maintenance and lack of maintenance, consequences - practically and in terms of money (early, high spare consumption and production loss).

  A separate/parallel course, at this stage, for managers down to chief operators is highly recommended, whereby the following is worked out:

  - cost of scheduled maintenance and spares;

- monitoring/accounting of scheduled maintenance, repairs and spares and budgeting for the same;
- economic consequences/financial analysis caused by production loss, additional major overhauls and shorter lifetimes;
- routines and monitoring for the service and maintenance is worked out;
- organization, responsibilities and incentives to make it work;
- presentation of the course and findings to the rest of the staff.

- Apply the above to the actual plant/activity.
  Log books, manuals, service routines, daily, weekly, monthly etc and work out routines that works independently of the level of the staff.

- Organize the staff accordingly.

General course in service and maintenance

This course should be carried out soon after the general course and be supervised by the project manager and a qualified engineer with experience from the actual field. All staff down to operators should be attending the course and the plant consequently shut down to stress the importance.

- General use of hand tools, including storekeeping.

- "Bolts and screws".
  Torques, practical demonstration of the strength of different threads and sizes, rusted and clean threads, matching threads etc.

- Flanges, lids and gaskets - basic theory and practical handling.
  (Very important for a producer gas plant and this section applies as much to the managers.)

- Handling of gaskets and their repair and substitutes.

- Loose bolts and nuts - consequences and maintenance routines.
  The same comment, as in the bracket above, applies.

- Apply the above to the actual plant and operation.
  This sounds very simple, but the experiences prove that loose, missing or wrongly tightened bolts and gaskets can cause severe damage to the equipment.

- General engine maintenance.

- Maintenance of the gas cleaning equipment.
  This is a very important part and detrimental to the lifetime and performance

of the engine and the consequences must be made clear to the operators.

- General maintenance of all the components of the plant.

- Log books, routines and responsibilities for the service and maintenance.

Applied service, repair and maintenance courses

With time, when the first repairs occur and a picture of the "weak spots" (of both plant and staff) begin to crystallize, shorter courses with relevant staff should be carried out, emphasizing the experiences gained.

- Go back to the manuals and try to find out when the malfunctioning started and what has caused it and why. What could have been done and what to do now? This will stress the importance of good record keeping and stimulate the staff.

- Train the staff in the relevant field.
  The training will, by now, likely be more applied to specific fields, like engine overhaul, repairs and manufacturing of simpler parts (substitutes for the filters used etc.).

- Stress and train the staff to look into possibilities to improve, modify or use other methods, local material etc.

Besides formal/organized courses the management should continuously follow up and train the staff in service and maintenance.

3. Monitoring

The monitoring applies to all levels and stages and depends on the activity and expected outcome. However, general monitoring like logbooks on daily operation, service, maintenance etc applies to any operation, as earlier indicated.

The importance of keeping accurate and continuous records seems to be very difficult to implement. A lot of information for the R&D is hereby lost.

The first log books to be opened are on service and maintenance. This book should show what and when done and by whom, what used/replaced. The store keeper should keep records on the equivalent spares used and in stock.

To be able to follow the maintenance instructions, there must be a log book on the daily operation.

For this type of activity a daily log sheet is very important. The records should cover hours operated, in and outputs, temperatures, pressure drops, feedstock used etc. These log sheets give very valuable information for the evaluation of the technique. This monitoring helps the operators to see when the plant is operating well and when something is malfunctioning. Besides all the valuable information that can be drawn, the monitoring itself is a good training for more advanced testing programmes.

It has been learnt that the monitoring itself contributes substantially to the training and education, especially of the least trained staff.

The training programmes, presented in /9/, together with the manufacturer's manuals form a good guide line on what kind of monitoring applies to operation of a producer gas operated plant.

The most difficult training component, which is not part of this chapter, is the training of the managers to continuously follow up the monitoring/record keeping. This is likely the main reason whenever proper records are not kept.

It can be concluded that the training of monitoring is very important and the skill should be gradually built up by initially keeping simple daily log sheets, for monitoring of advanced tests. To maintain continuity in the monitoring, it is of outmost importance that the monitoring is followed up by the managers and that feedback is given to the ones monitoring, all to correct and motivate the monitoring.

4. Training related to the producer gas technique

Local gasification training course

This course, which could include all staff plus a few technicians and engineers within the daughter/sister organizations/companies, should be conducted by the project manager assisted by an experienced gasification engineer (expert).

The one or two day course should explain the basics of gasification applied on the actual plant and application.

The aim is to train the staff to understand the process and link this to the design, service and maintenance, fuel preparation etc at site. The ultimate goal is to motivate (to feel part of and proud of the development) and train the staff to actively take part in the improvement, development and dissemination of the technique.

Relevant sections, i.e only those ones that apply to the actual plant, from the conducted training course/seminar /10/ form a good guidance for the contents of this local gasification training course.

These courses can preferably be repeated and gradually dive delve into the subject.

National gasification training course (and seminar)

This type of courses can be extended to involve tentative users, technical schools and universities and even become a subject on the school scheme. It is only the funds and time that sets the limits.

However, the technique is not "high tech", but a new technique to most of the developing countries. From this point of view it is very important, for a successful introduction and dissemination, that active and extensive training is carried out in fields where the technique is likely to be introduced.

A good guidance for the contents and frames of the course(s) is the training course carried out during the present project /10/, but extended to two weeks and with approximately 20 participants. The course should be tailored to the backgrounds of the participants and the local conditions. The course should further include case studies from the participants' countries.

The course(s) could also include seminars, which are not part of the training programme, however.

Safety aspects

Since the producer gas is a deadly poisonous gas, instructions and explanation of the process, operation, handling etc, in this respect, should be gone through at a very early stage of the project. The first information has to be given before the first start-up of the plant.

The safety regulations and precautions, including ordinary industrial aspects, should be followed up periodically.

5. Modification and manufacturing

A pilot gasification demonstration programme can not cover nor provide workshop and manufacturing training as such. A substantial training component in this respects is a normal spin-off effect, however, especially for projects running over longer periods with resources and time for local modification and manufacture.

To be able to carry out R&D and thereby modify and improve a plant, the feedback from the permanent staff is of outmost importance. The training mentioned ion Paragraph 4 is referred.

As far as producer gas plants are concerned, in general, there is lots of information from short tests and from the first few hundred hours of operation. When it comes to long term tests, the results and the reliability of the records are limited. Some of the main reasons are related to the management and the maintenance.

The actual technique could really make a step forward if higher degree of sustainability in the operation and monitoring could be achieved. The long term tests can hardly be carried out by senior (foreign) staff, since the labour cost becomes too high. The tests, i.e daily operation under controlled conditions, have to be carried out with ordinary operators, perhaps strengthened with a local engineer, due to the nature of the project.

Thus, the training, as far as modification and manufacturing is concerned, should rather be stressing the conditions that can create an atmosphere whereby a meaningful, sustainable and systematic development of the technique, through or ending up in local modifications and manufacturing, can take place.

From the above, we can see that we are back to the fact, that the ultimate responsibility is on the management to make sure that records are kept and instructions are followed. However, unless there is no feedback from the managers to the operators, the routines tends to drop back "to square one".

There are many cases when modifications have been done, but due lack of reliable records or sporadic records or operation, very limited conclusions can be drawn from the change. Other factors like that the originally trained and skilled staff have left the projects contribute to the trend.

The sporadic observations mentioned above, indicate many factors that are normally not considered and that are difficult to include in a training programme.

To propose some kind of guidance on a training programme, the following has been found to have a positive influence on the sustainability and outcome:

- Budget and schedule for local manufacturing of a plant within a few years from start.

- Work actively, i.e involve and include all the key people, towards the goal to have one ("own") plant manufactured locally.

- Continuous monitoring and relating the results to the activity and to the proposed and done modifications.

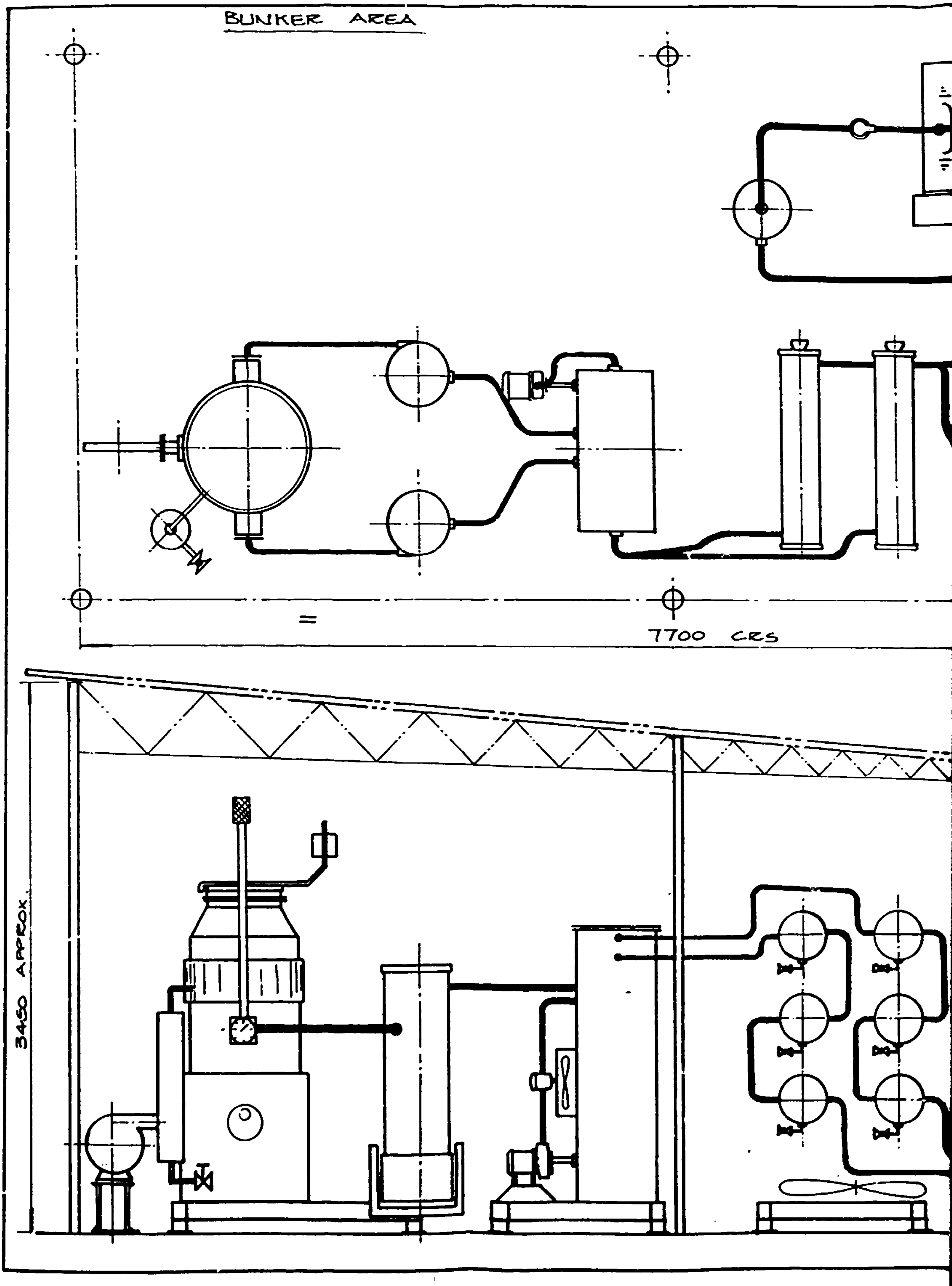
- Train the staff to read the records and make the monitoring meaningful by introduction of, for instance, an incentive system. Perhaps a certain percentage on diesel oil saved.

- Periodical follow-up by qualified staff (foreign experts if necessary).

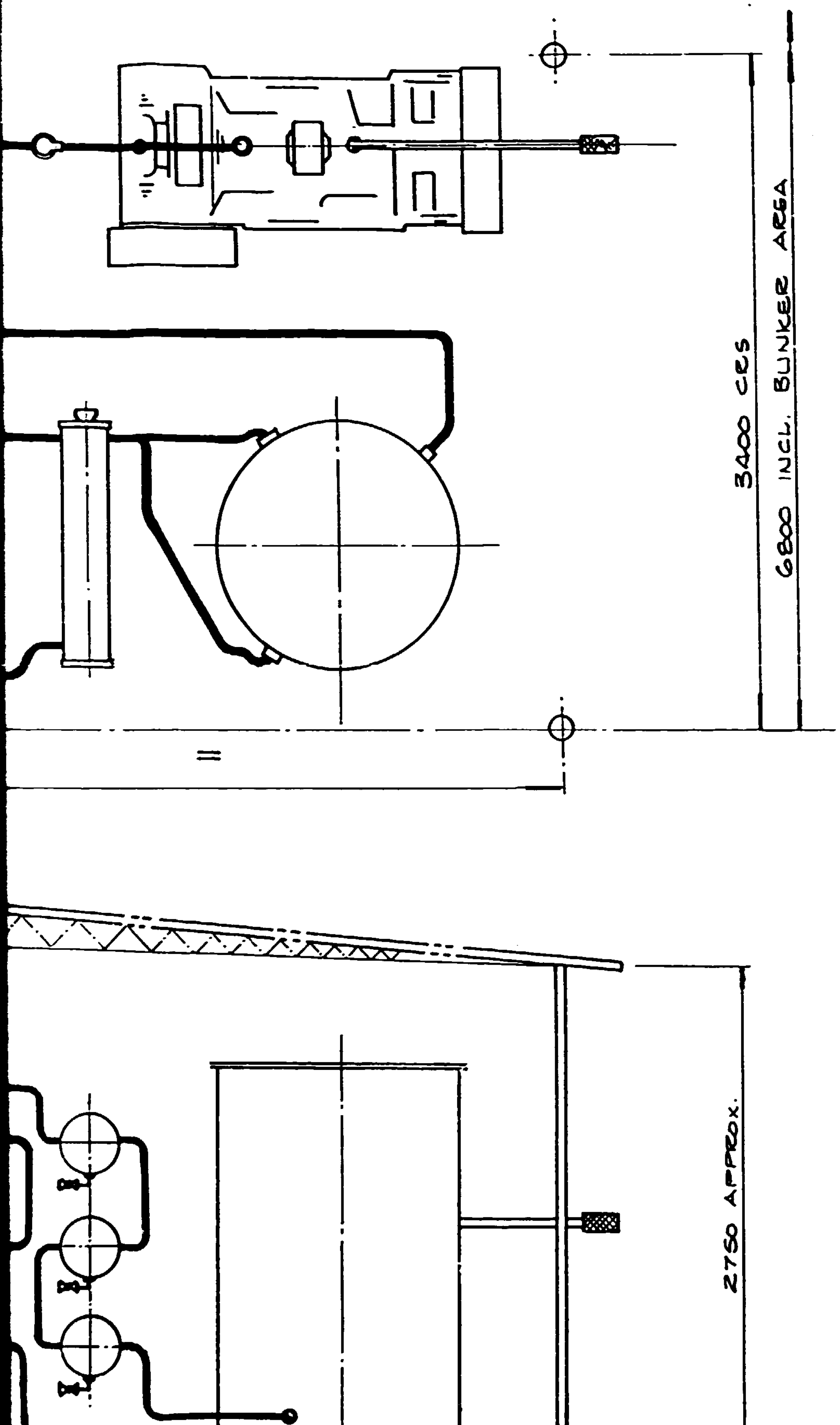
- Use a load for the plant which puts a pressure on the staff to operate the plant

- Introduce revolving funds for the service given (power delivered) and use some for the incentives.

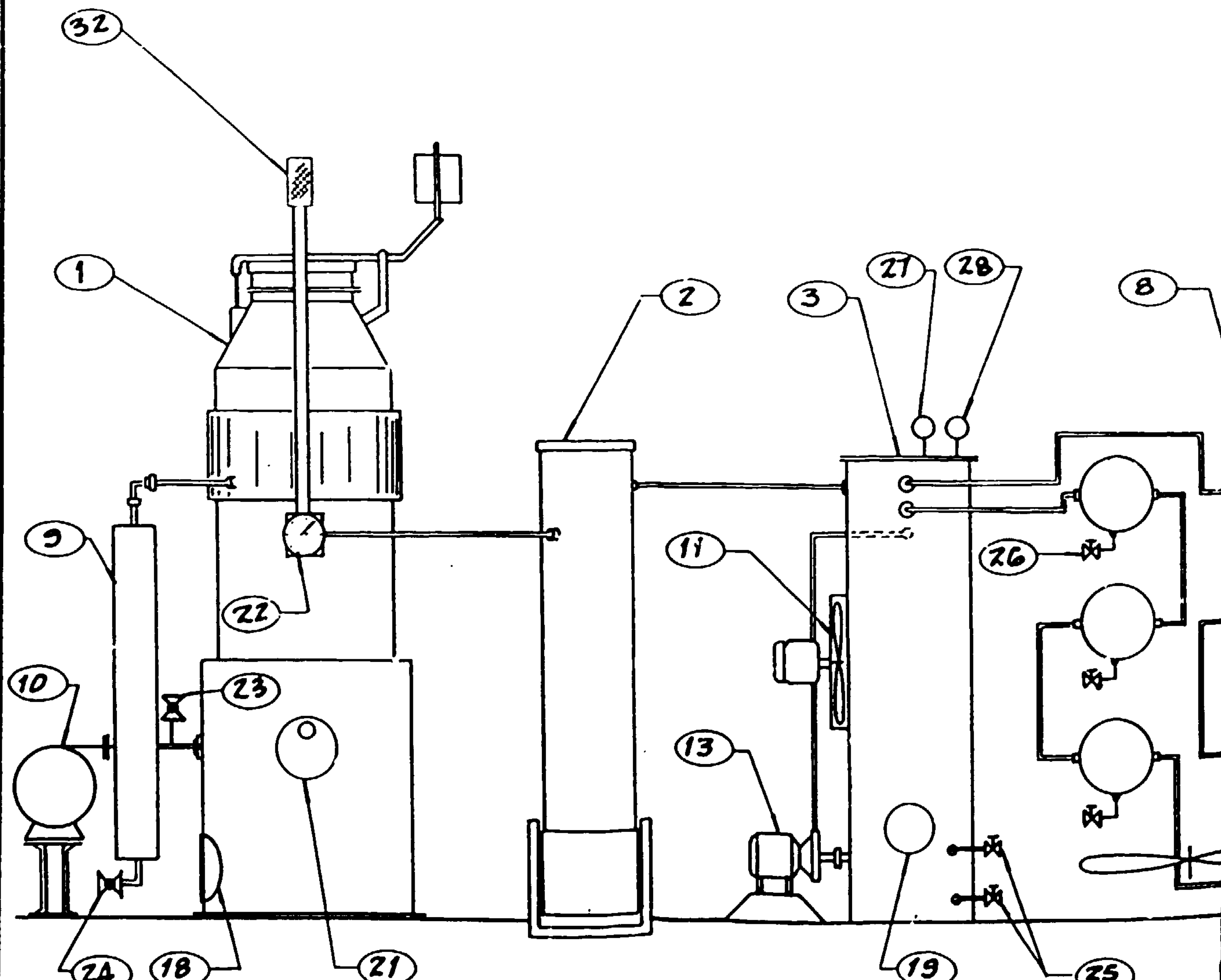
ANNEX F - TECHNICAL DATA ON SES GASIFICATION SYSTEM



SECTION 1



SITE LAYOUT
FIG 3.2.a
"ORIGINAL SES"



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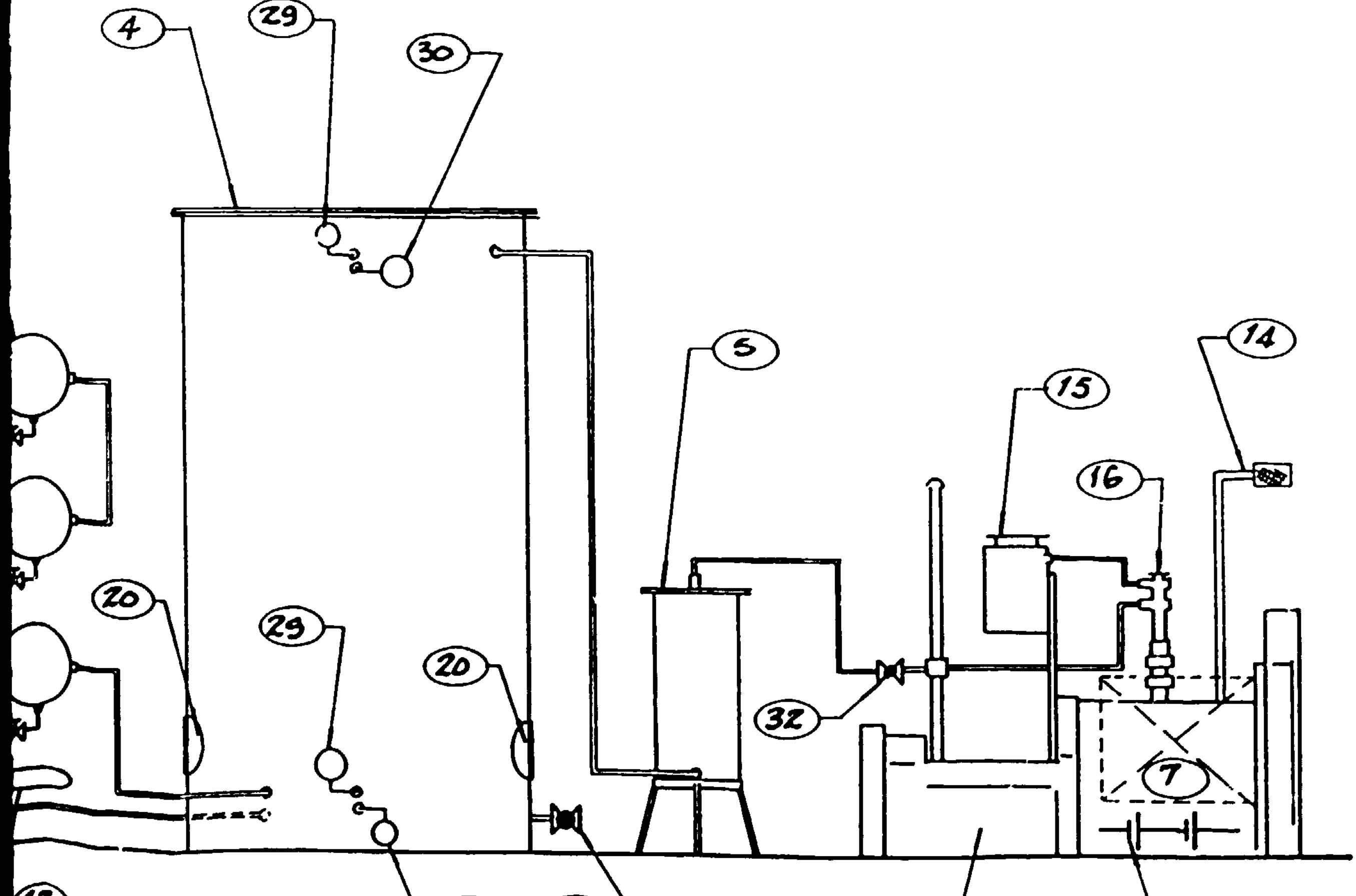
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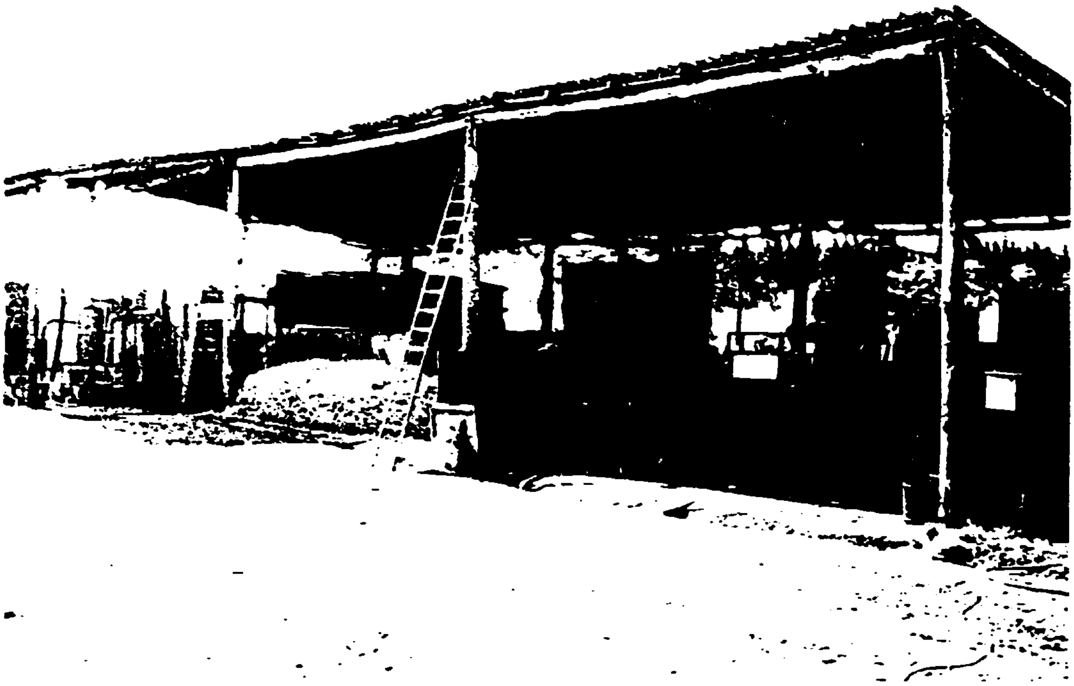
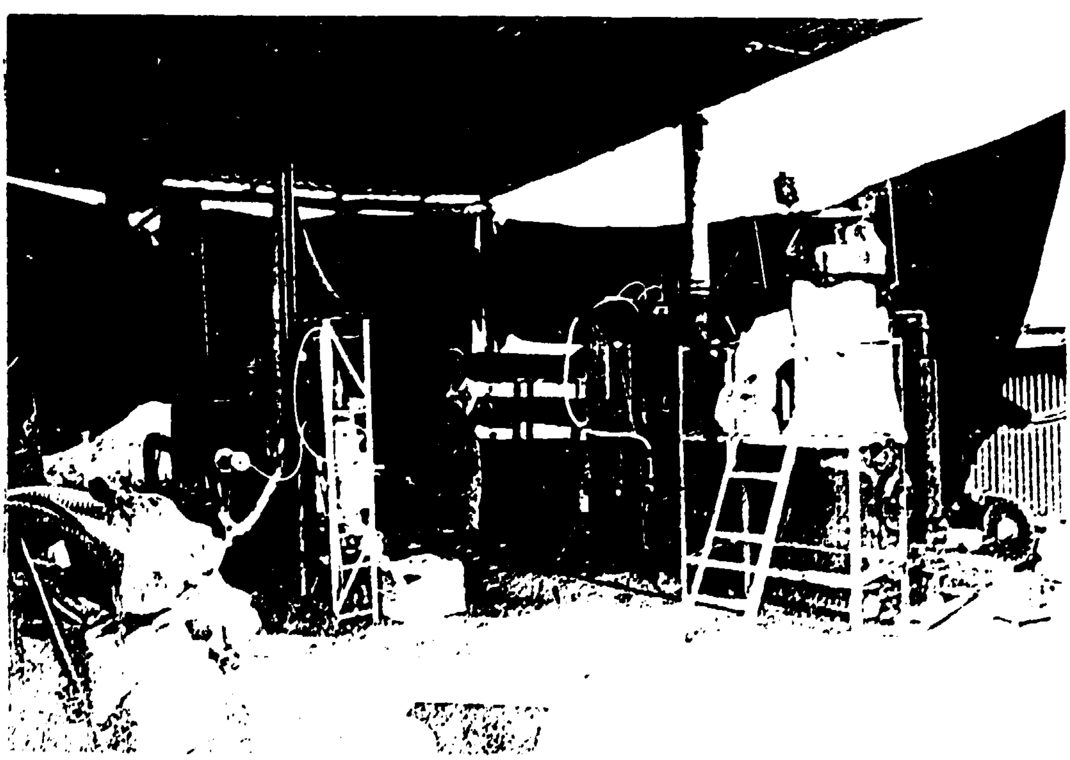
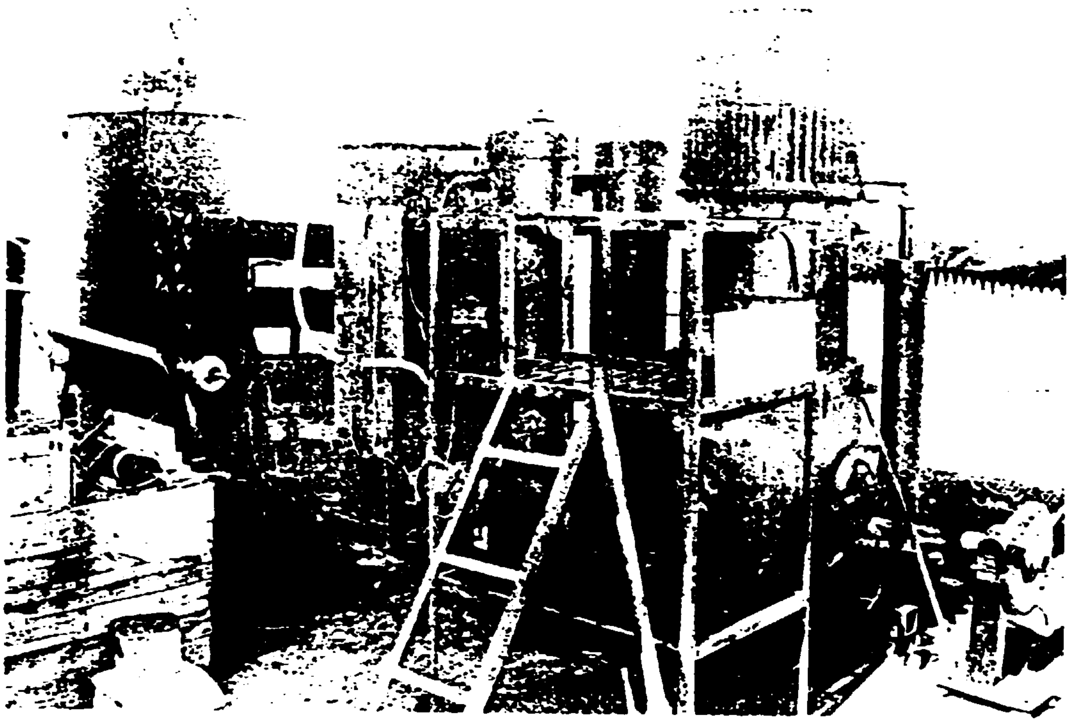
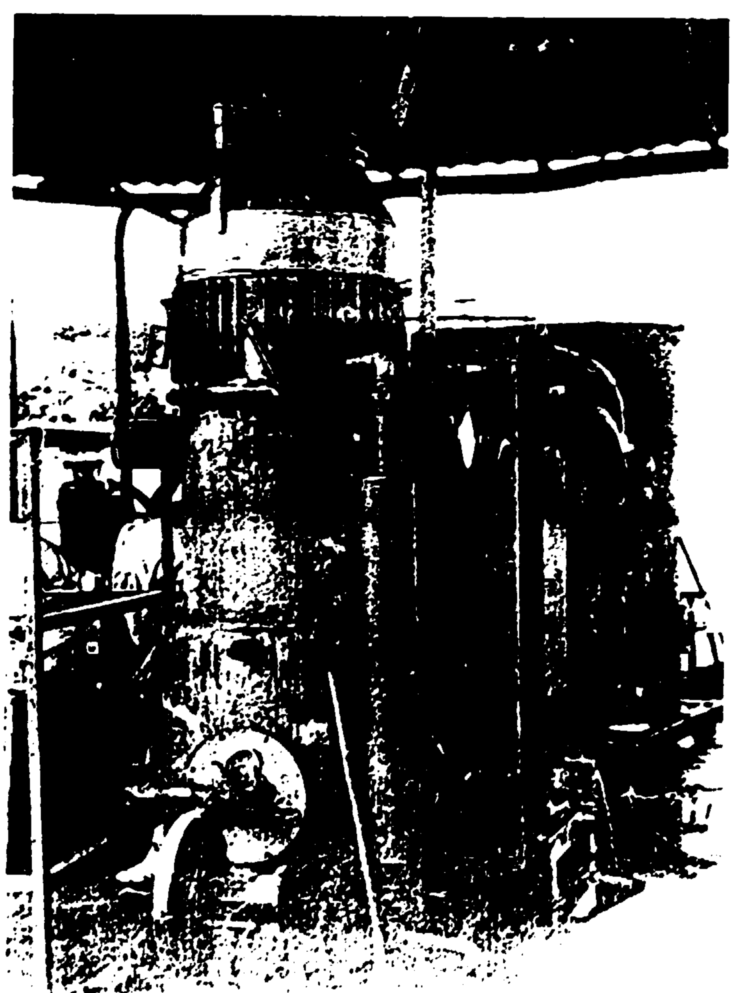
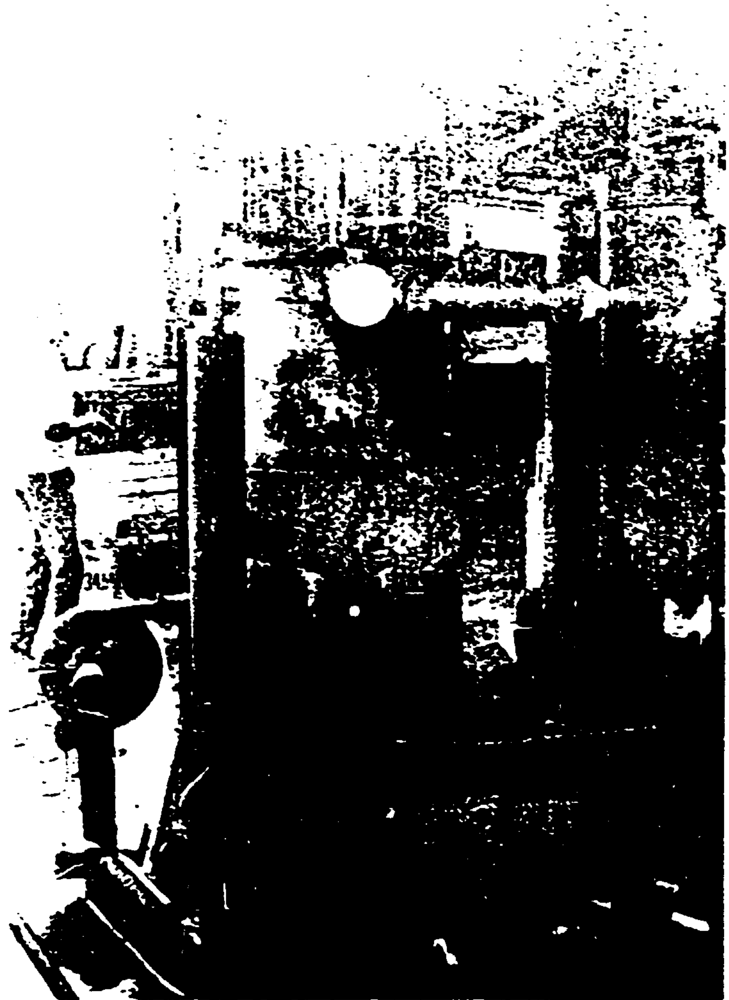
PRT NO	DESCRIPTION
33	
32	CONTROL VALVE
31	CONDENSATE DRAIN VALVE
30	PRESSURE GAUGE
29	TEMPERATURE GAUGE
28	PRESSURE GAUGE
27	THERMOMETER
26	FILTER DRAIN VALVES - 6 OFF
25	PRESSURE DRAIN VALVES
24	CONDENSATE DRAIN VALVE
23	AIR INLET VALVE
22	PRESSURE GAUGE
21	INSPECTION DOOR AND GLASS
20	SAWDUST REMOVAL DOORS
19	INSPECTION DOOR
18	ASH REMOVAL DOOR
17	BATTERY CELLS - 2 OFF x 12V Ea.
16	MIXING VALVE
15	AIR FILTER
14	EXHAUST
13	COOLING UNIT PUMP
12	DISK-TYPE FILTER FAN
11	COOLING UNIT FAN
10	AIR BLAST FAN
9	CONDENSER
8	DISK-TYPE FILTERS - 6-OFF MOUNTED 3 ROWS, 2 COLUMNS
7	CONTROL PANEL
6	ENGINE (TESSARI)
5	SAFETY FILTER
4	FINAL FILTER
3	COOLING UNIT
2	MECHANICAL FILTERING UNIT - 2-OFF
1	REACTOR

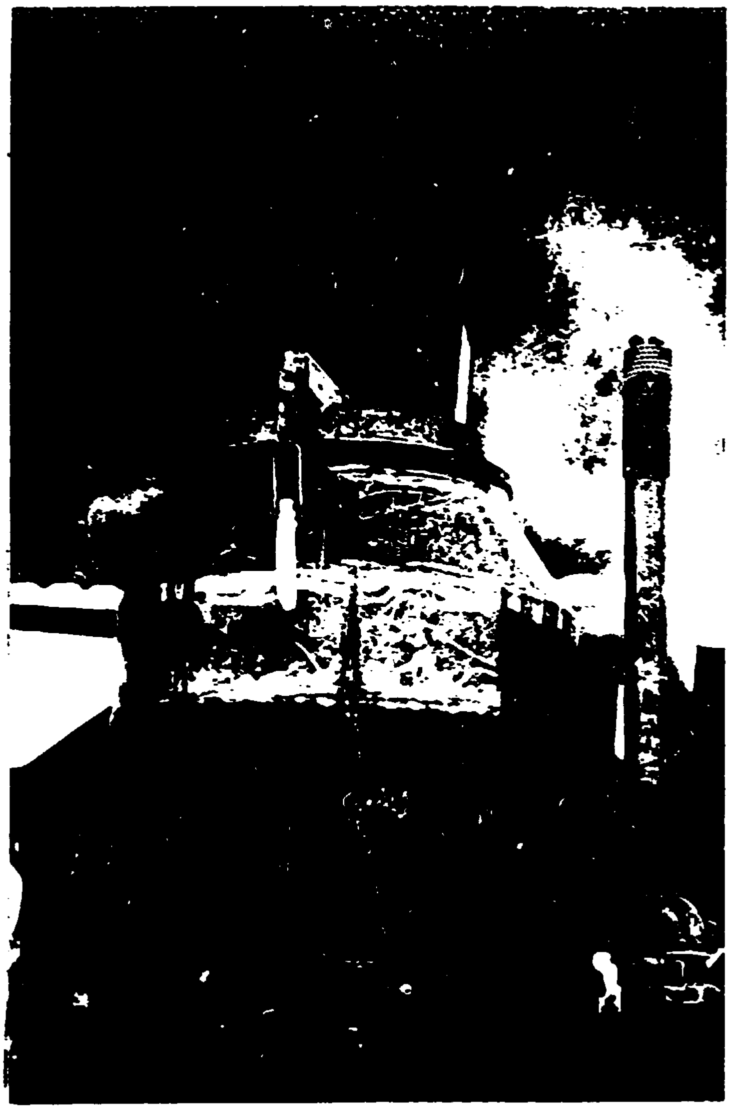


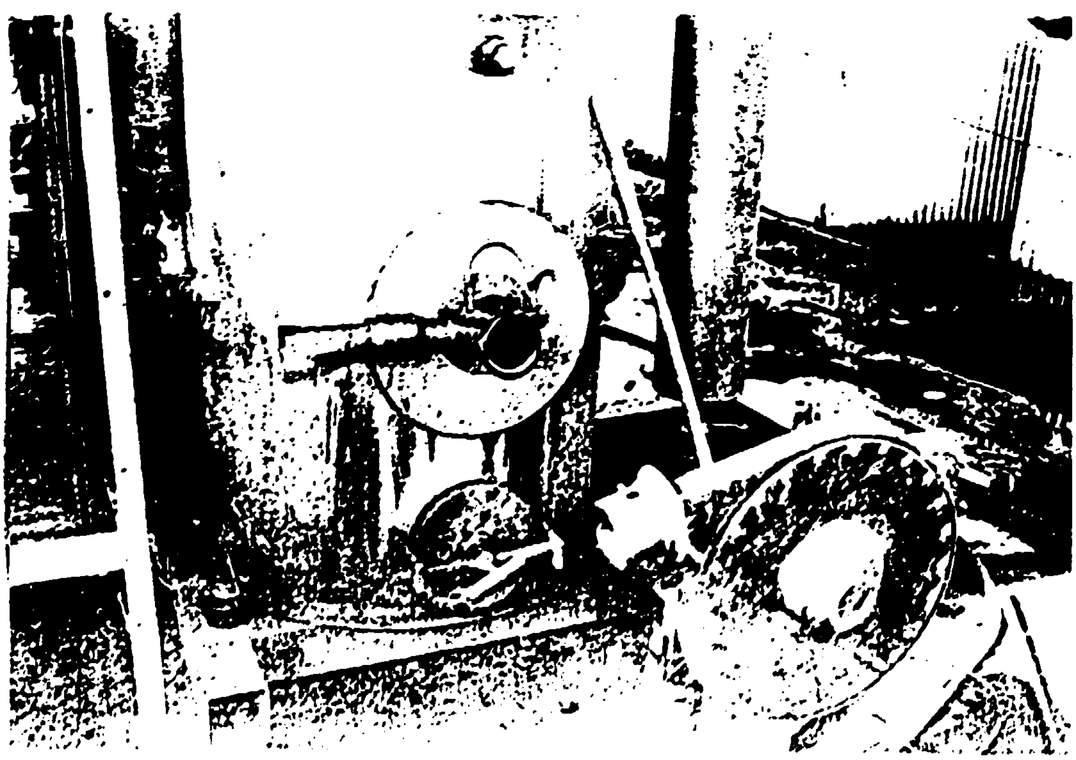




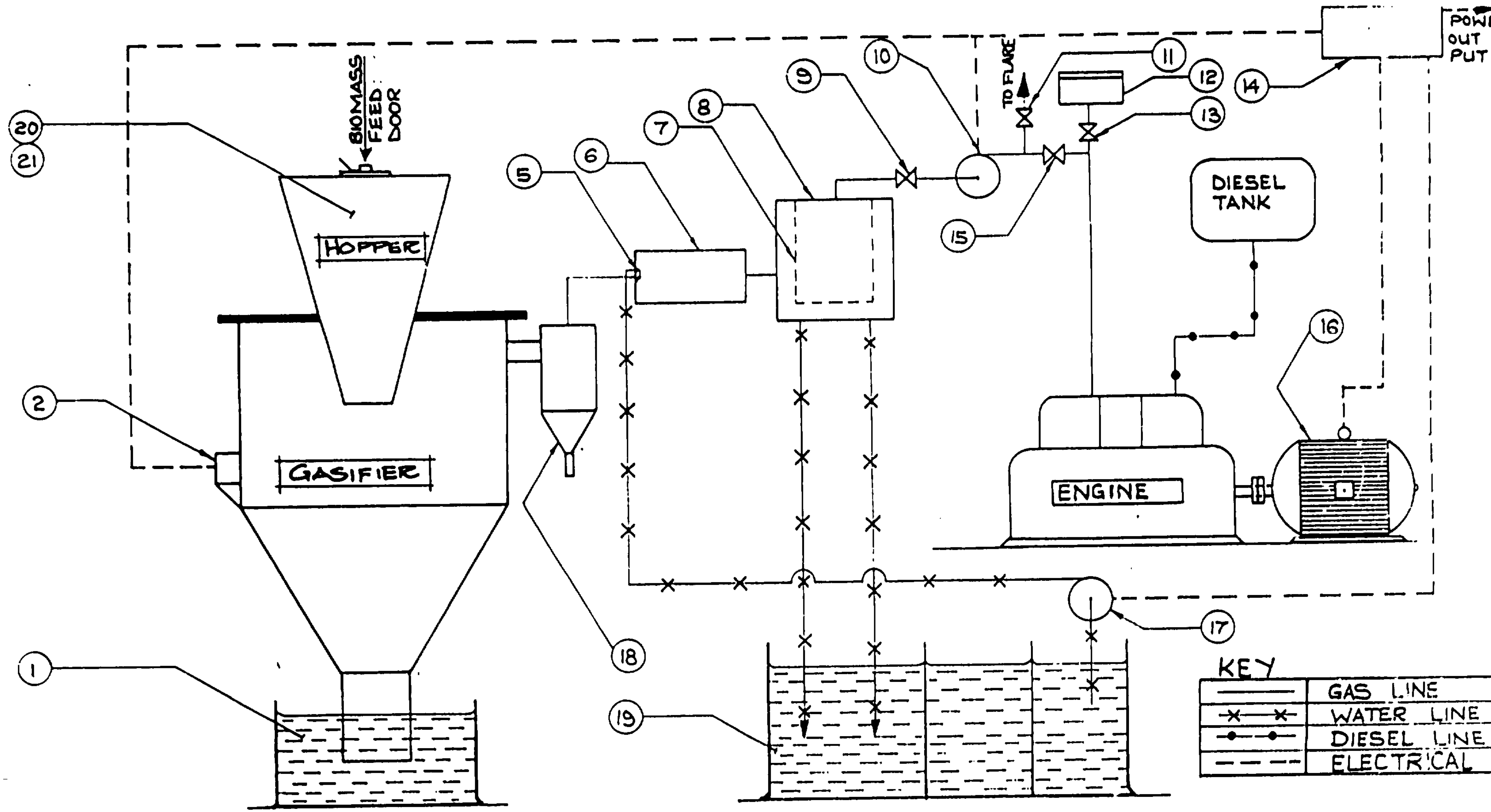








ANNEX G – TECHNICAL DATA ON ANKUR GASIFICATION SYSTEM



ANKUR GASIFIER
MODEL BG 40

Prt No.	DESCRIPTION
25	
24	
23	
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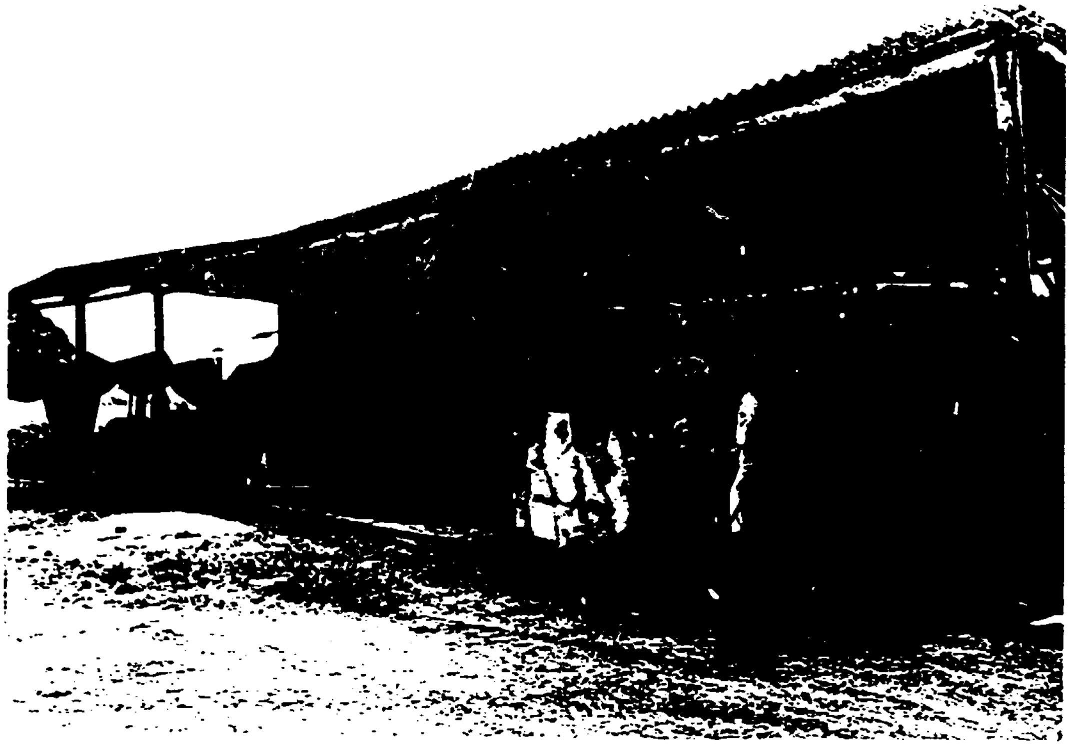
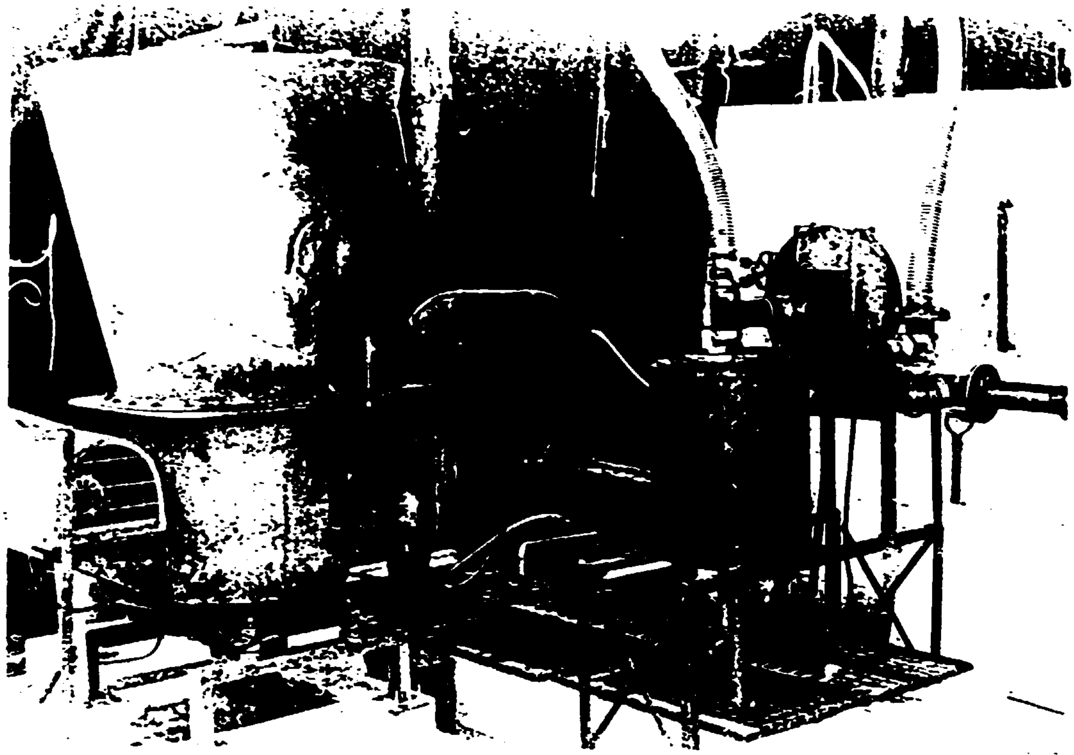
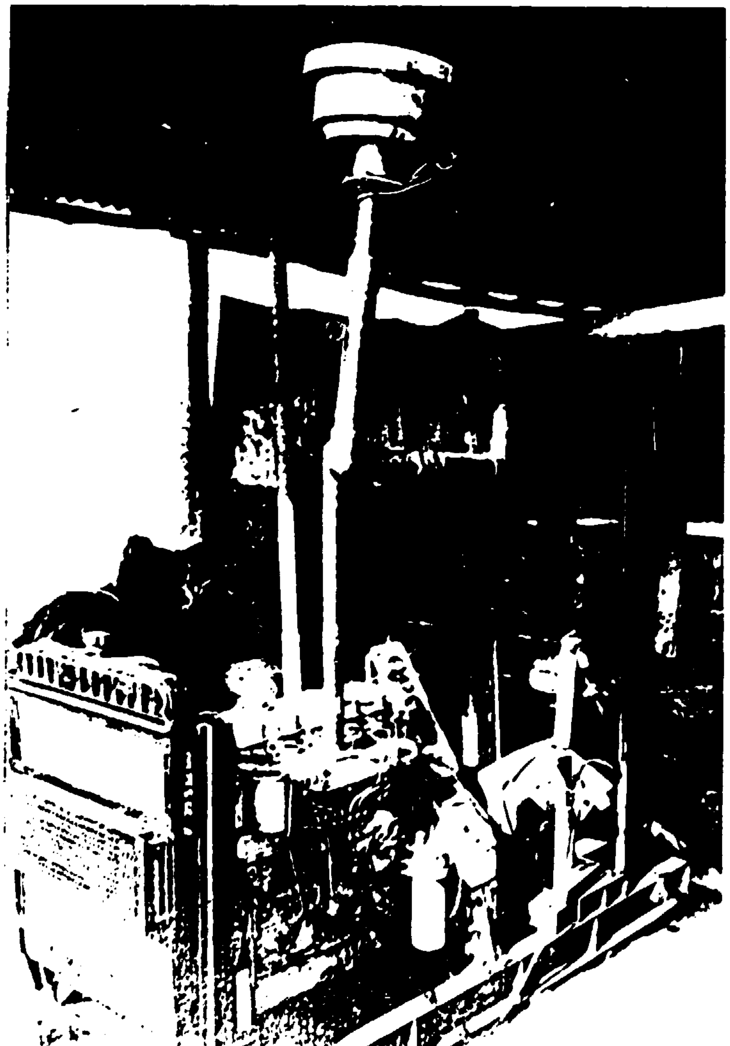
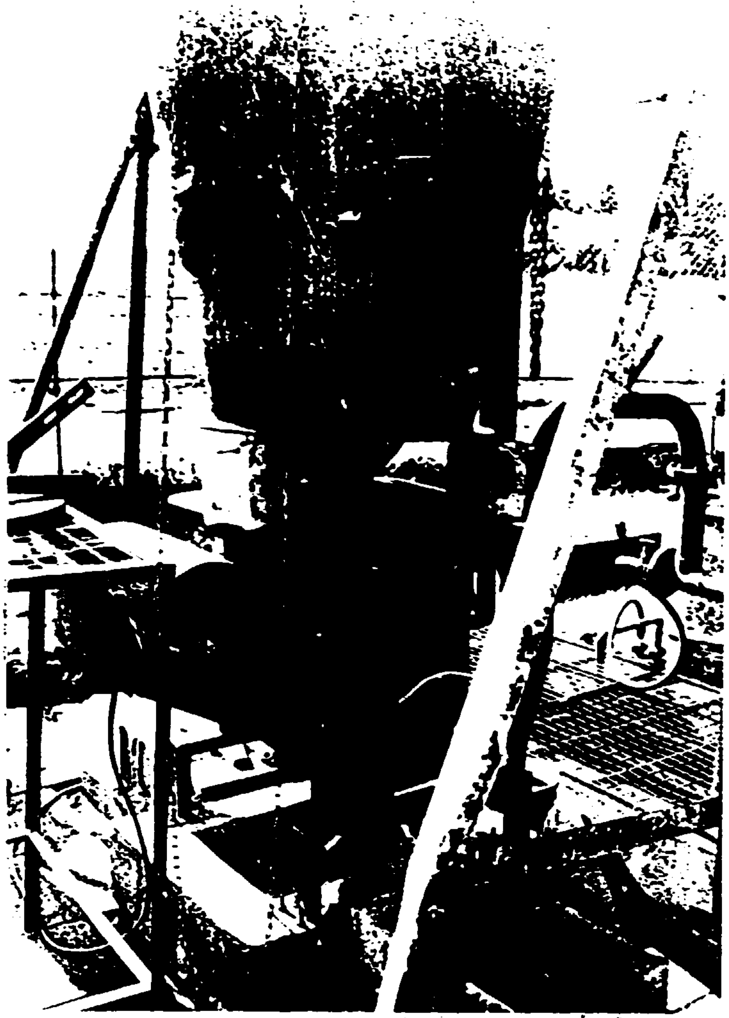
21	GASIFIER
20	HOPPER
19	COOLING AND FILTERING POND
18	CYCLONE
17	(MOTOR AND PUMP) SET FOR RECIRCULATION
16	ALTERNATOR
15	MAIN GAS VALVE
14	DISTRIBUTION PANEL
13	AIR VALVE
12	AIR FILTER
11	FLARE VALVE
10	BLOWER
9	PRE-SET VALVE
8	SEPARATOR BOX
7	FILTER
6	VENTURI SCRUBBER
5	SPRAY NOZZLE
4	
3	AIR NOZZLES
2	VIBRATOR
1	ASH POND

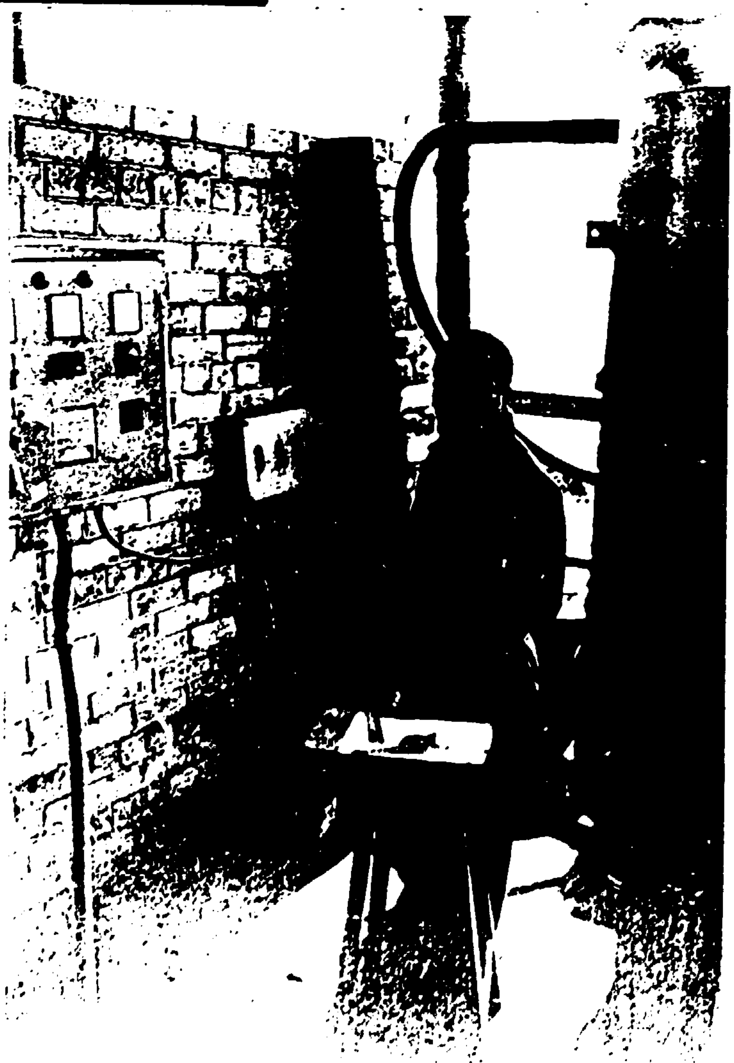
ANKUR GASIFIER



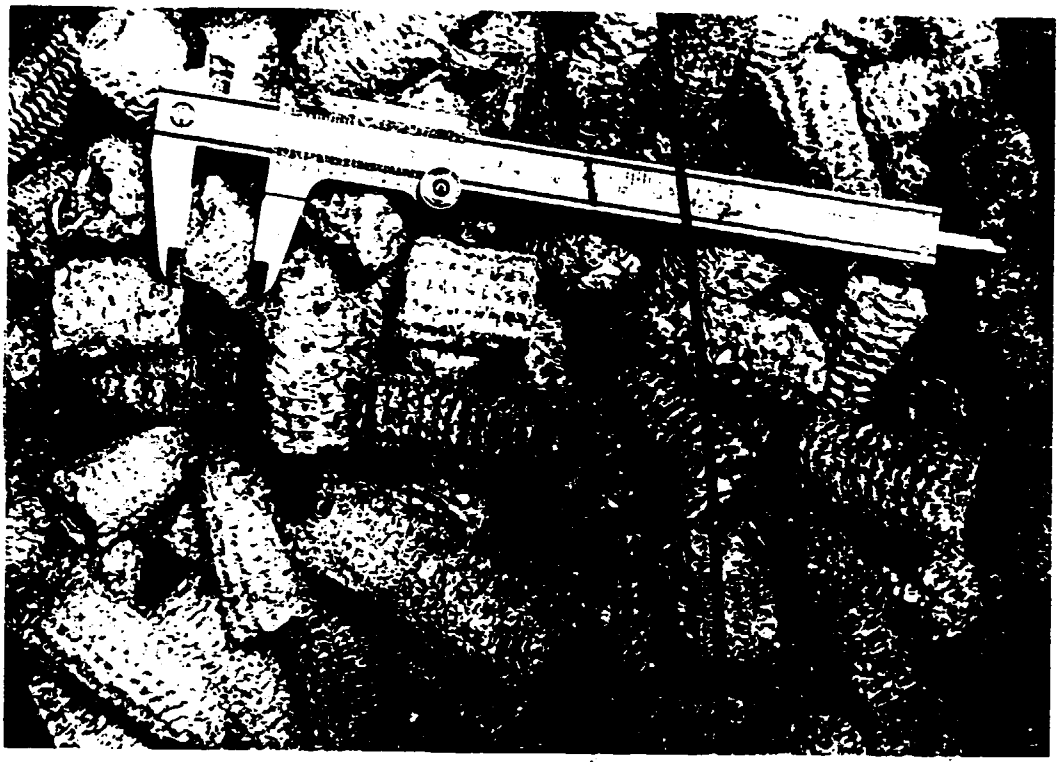


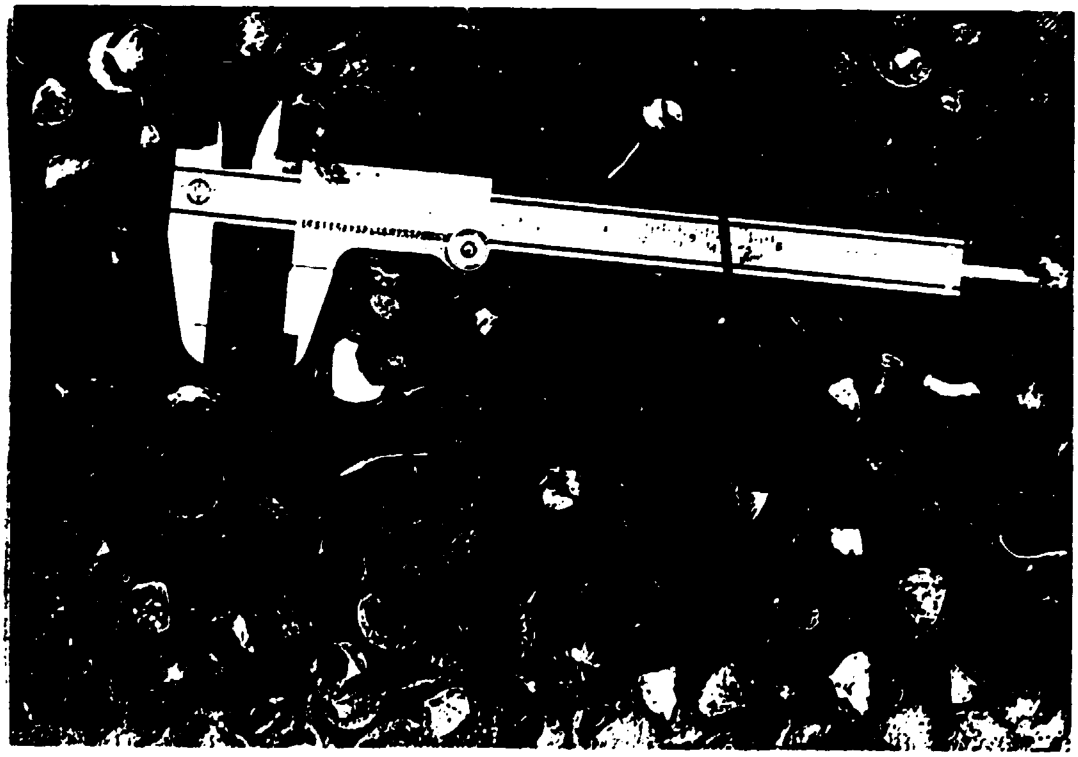


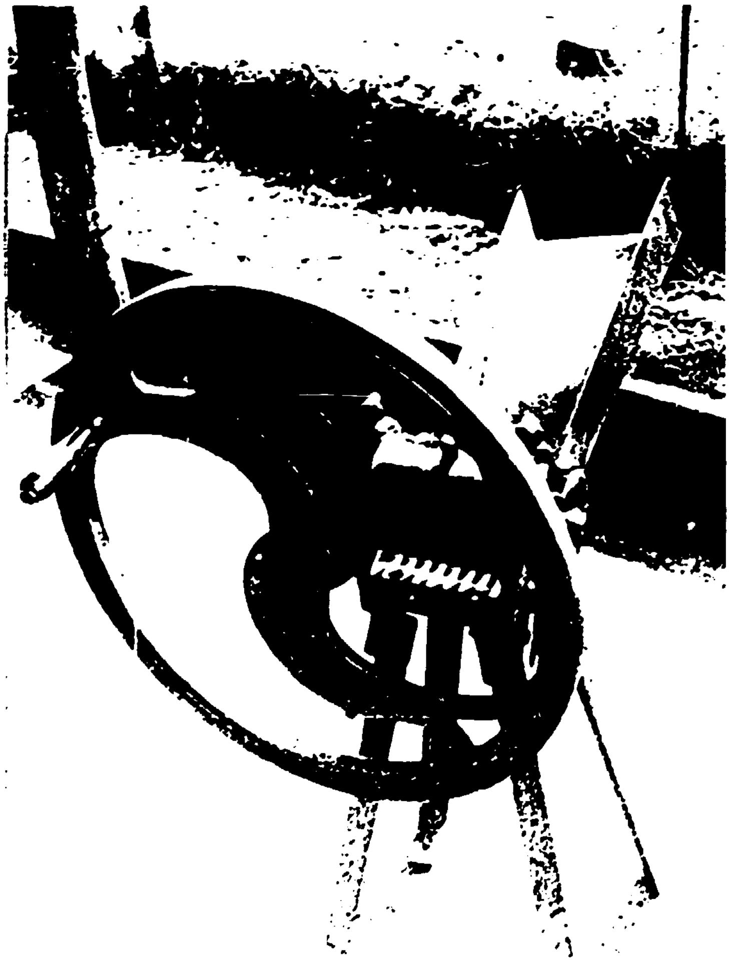




ANNEX H - PHOTOGRAPHS OF WASTES TESTES







ANNEX I - ENGINE OIL ANALYSIS

SCIENTIFIC WEAR AND OIL LIFE ANALYSIS

ZEMCO

TELEPHONE 47321

P.O. BOX 1537, HARARE

YOUR CATERPILLAR DEALER

CAT PLUS

UNIVERSITY OF ZIMBABWE.
ATT: MR. ASCOUGH.
P.O BOX MP167.
MOUNT PLEASANT.
HARARE.

Shop job number:
Shop segment number:
Equipment number: FIAT
Job site: MIJO ESTATES.
Unit manufacturer: FIAT
Unit model number: FW15
Unit serial number: FIAT FW15(SASIFIER).
Compartment: ENGINE
Oil brand/Mass:
Was oil changed at this sample time?
Customer purchase order:
Sample label number:
Laboratory control number: 1H15030
Overall sample evaluation: 4

Sample	Amt of oil acd.	SMU odom on unit	SMU odom. on oil		
..2691	2	692	169	Evaluation:	THE COMPARTMENT WEAR APPEARS TO BE NORMAL.
				Recommendation:	NO ACTION REQUIRED AT THIS TIME OIL IS SUITABLE FOR FURTHER USE
				Feedback:	
..0591	12	583	272	Evaluation:	IRON IS EXTREMELY HIGH. ALUMINUM IS EXTREMELY HIGH. ALL OTHER ELEMENTS TEST RESULTS APPEAR NORMAL.
				Recommendation:	POSSIBLE RING AND LINER WEAR. SUGGEST CHANGING OIL AND FILTER(S). SAMPLE REGULARLY TO MONITOR
				Feedback:	
..591	3	709.63		Evaluation:	THE COMPARTMENT WEAR APPEARS TO BE NORMAL.
				Recommendation:	NO ACTION REQUIRED AT THIS TIME OIL IS SUITABLE FOR FURTHER USE
				Feedback:	
..591	NS	709.64		Evaluation:	IRON IS SLIGHTLY HIGH. ALL OTHER ELEMENTS TEST RESULTS APPEAR NORMAL.
				Recommendation:	NO ACTION REQUIRED AT THIS TIME OIL IS SUITABLE FOR FURTHER USE SAMPLE REGULARLY TO MONITOR
				Feedback:	

Concentrations in PPM — Oil condition/Contaminants

Sample	CU	FE	CR	PB	AL	SI	MO	NA	MG	SN	W	F	A	ST	OXI	NIT	SUL	VIS
..691	9	197	2	1	16	1					NIL	NIL		NIL	7%		20%	
..591	9	536	2	4	71	2					NIL	NIL		NIL	NIL		17%	
..591	12	10	7		19	6					NIL			NIL	10%		27%	
..591	3	440	5		2	9					NIL			NIL	12%		7%	

WEAR METAL ABBREVIATIONS

AL - ALUMINUM | CU - COPPER | SI - SILICON | W - WATER | ST - SOOT | OX - OXIDATION
CR - CHROMIUM | PB - LEAD | NA - SODIUM | F - FUEL | SU - SULPHUR | NI - NITRATION
FE - IRON | MO - MOLYBDENUM | | A - ANTIFREEZE | VI - VISCOSITY |

[illegible]

SCIENTIFIC WEAR AND OIL LIFE ANALYSIS

ZEMCO
TELEPHONE 47321
P.O. BOX 1537,
HARARE
YOUR CATERPILLAR DEALER

CAT PLUS

UNIVERSITY OF ZIMBABWE.
ATT:MR.ASCOUGH.
P.O BOX MP162.
MOUNT PLEASANT.
HARARE.

Shop job number:	
Shop segment number:	
Equipment number:	LEYLAND
Job site:	NIJO ESTATES.
Unit manufacturer:	L/LAND
Unit model number:	ALU370
Unit serial number:	LEYLAND (GASIFIER).
Compartment:	ENGINE
Oil brand/Mass:	MOBIL SUPER/40
Was oil changed at this sample time?:	
Customer purchase order:	
Sample label number:	
Laboratory control number:	1C04676
Overall sample evaluation:	A

Date	Am't of add. oil	SMU odom. on unit	SMU odom. on oil		
891				Evaluation:	THE COMPARTMENT WEAR APPEARS TO BE NORMAL.
				Recommendation:	NO ACTION REQUIRED AT THIS TIME OIL IS SUITABLE FOR FURTHER USE
591	NG	165	165	Feedback:	Clean [illegible] oil
891				Evaluation:	THIS SAMPLE CONTAINS EXCESS FUEL DILUTION. WEAR METALS AND SILICON APPEAR ABOVE NORMAL. CHECK FOR DIRT ENTRY
				Recommendation:	CHECK INJECTORS AND OR OVERFUELING. SUGGEST CHANGING OIL AND FILTER(S). SAMPLE REGULARLY TO MONITOR
591	5	165	165	Feedback:	
				Evaluation:	
				Recommendation:	
				Feedback:	
				Evaluation:	
				Recommendation:	
				Feedback:	

Concentrations in PPM / Oil condition/Contaminants

	CU	FE	CR	PB	AL	SI	MO	NA	MG	SN	W	F	A	ST	OXI	NIT	SUL	VIS
91	0	272	0		2	0					NIL			NIL	3%		7%	
91	68	521	1	35	41	17					NIL	+3%		50%	7%		37%	

WEAR METAL ABBREVIATIONS

AL - ALUMINUM
CR - CHROMIUM
FE - IRON
CU - COPPER
PB - LEAD
MO - MOLYBDENUM
SI - SILICON
NA - SODIUM
W - WATER
F - FUEL
A - ANTIFREEZE
ST - SOOT
SU - SULPHUR
VI - VISCOSITY
OX - OXIDATION
NI - NITRATION

→ L. Palm

SCIENTIFIC WEAR AND OIL LIFE ANALYSIS

ZEMCO

TELEPHONE 47321 P.O. BOX 1537. HARARE

YOUR CATERPILLAR DEALER

CAT PLUS

Shop job number:
Shop segment number:
Equipment number:
Job site:
Unit manufacturer:
Unit model number:
Unit serial number:
Compartment:
Oil brand/Mass:
Was oil changed at this sample time?:
Customer purchase order:
Sample label number:
Laboratory control number:
Overall sample evaluation:

Sample	Am't. of add. oil	SMU odom. on unit	SMU odom. on oil		
				Evaluation:	wear metals appear higher than normal
				Recommendation:	Change oil immediately CURRENT
				Feedback:	
				Evaluation:	normal PREVIOUS
				Recommendation:	#1
				Feedback:	
				Evaluation:	excess fuel dilution PREVIOUS
				Recommendation:	#2
				Feedback:	
				Evaluation:	PREVIOUS
				Recommendation:	
				Feedback:	

Concentrations in PPM: Oil condition/Contaminants

515

272

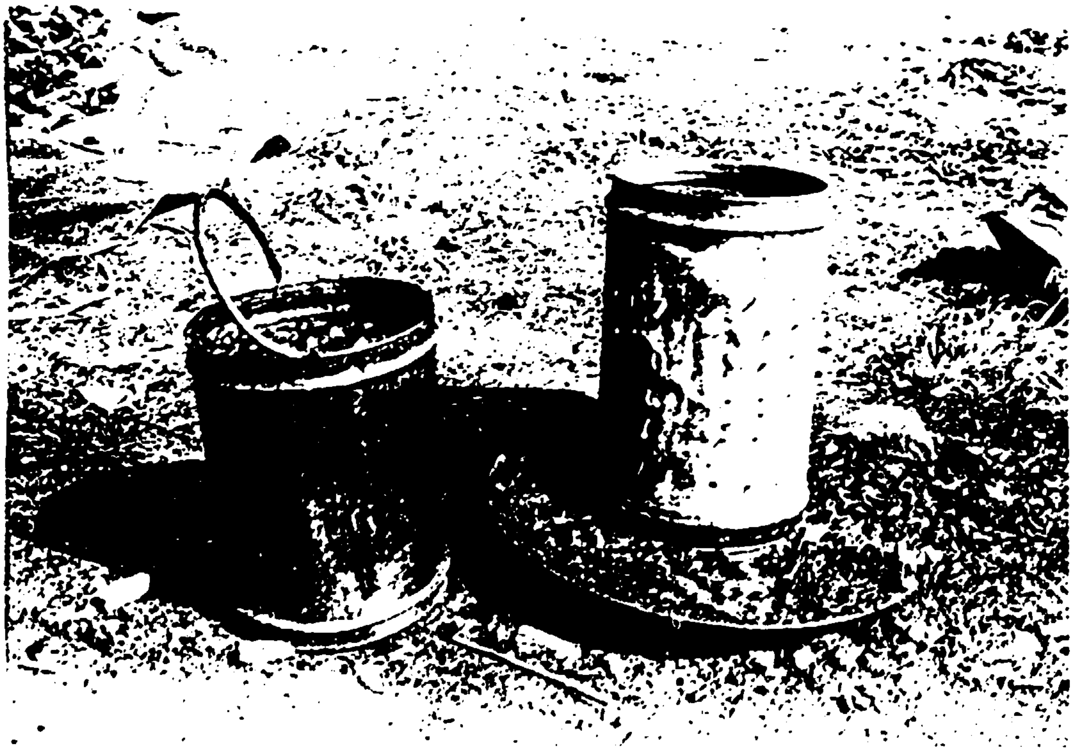
521

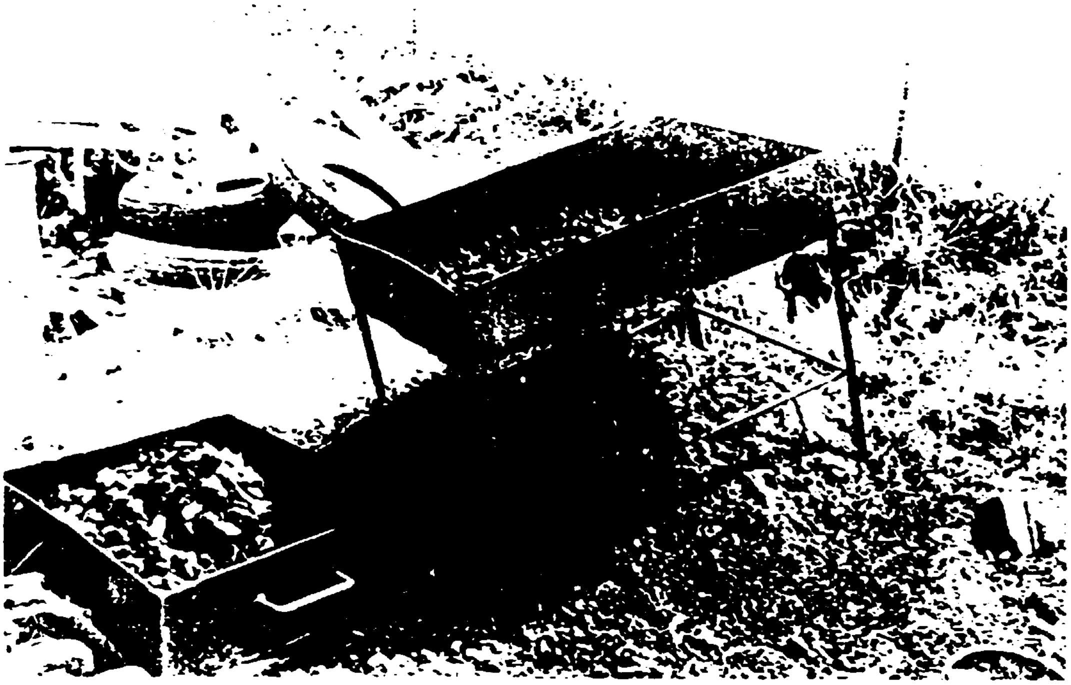
WEAR METAL ABBREVIATIONS

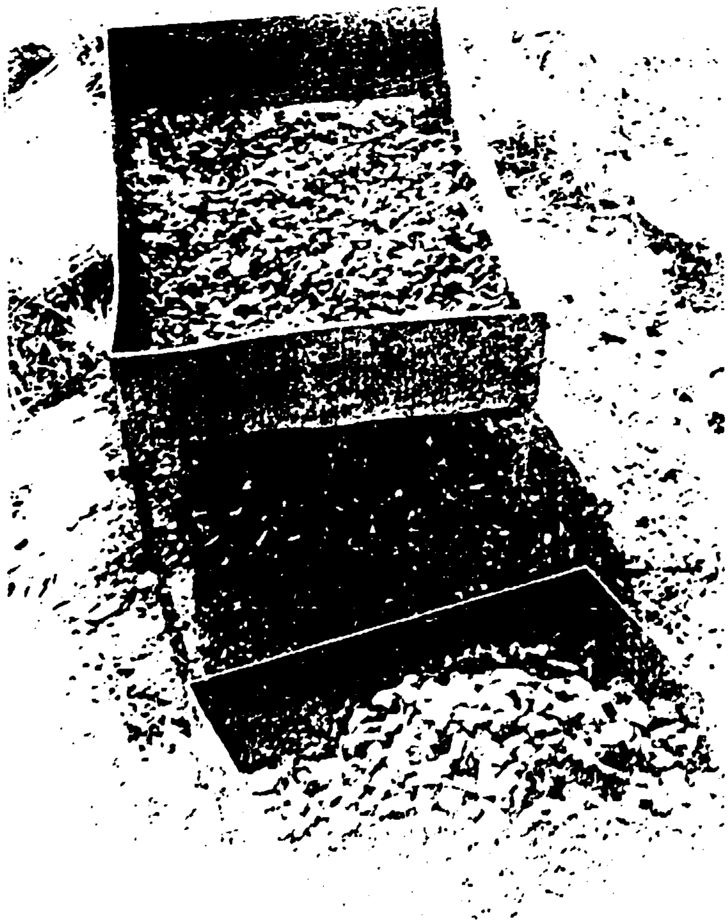
AL – ALUMINUM
CR – CHROMIUM
FE – IRON
CU – COPPER
PB – LEAD
MO – MOLYBDENUM
SI – SILICON
NA – SODIUM
W – WATER
F – FUEL
A – ANTIFREEZE
ST – SOOT
SU – SULPHUR
VI – VISCOSITY
OX – OXIDATION
NI – NITRATION

THIS ANALYSIS IS INTENDED AS AN AID IN PREDICTING MECHANICAL WEAR. NO GUARANTEE, EXPRESS OR IMPLIED, IS MADE AGAINST FAILURE OF THIS PIECE OF EQUIPMENT OR A COMPONENT PART THEREOF.

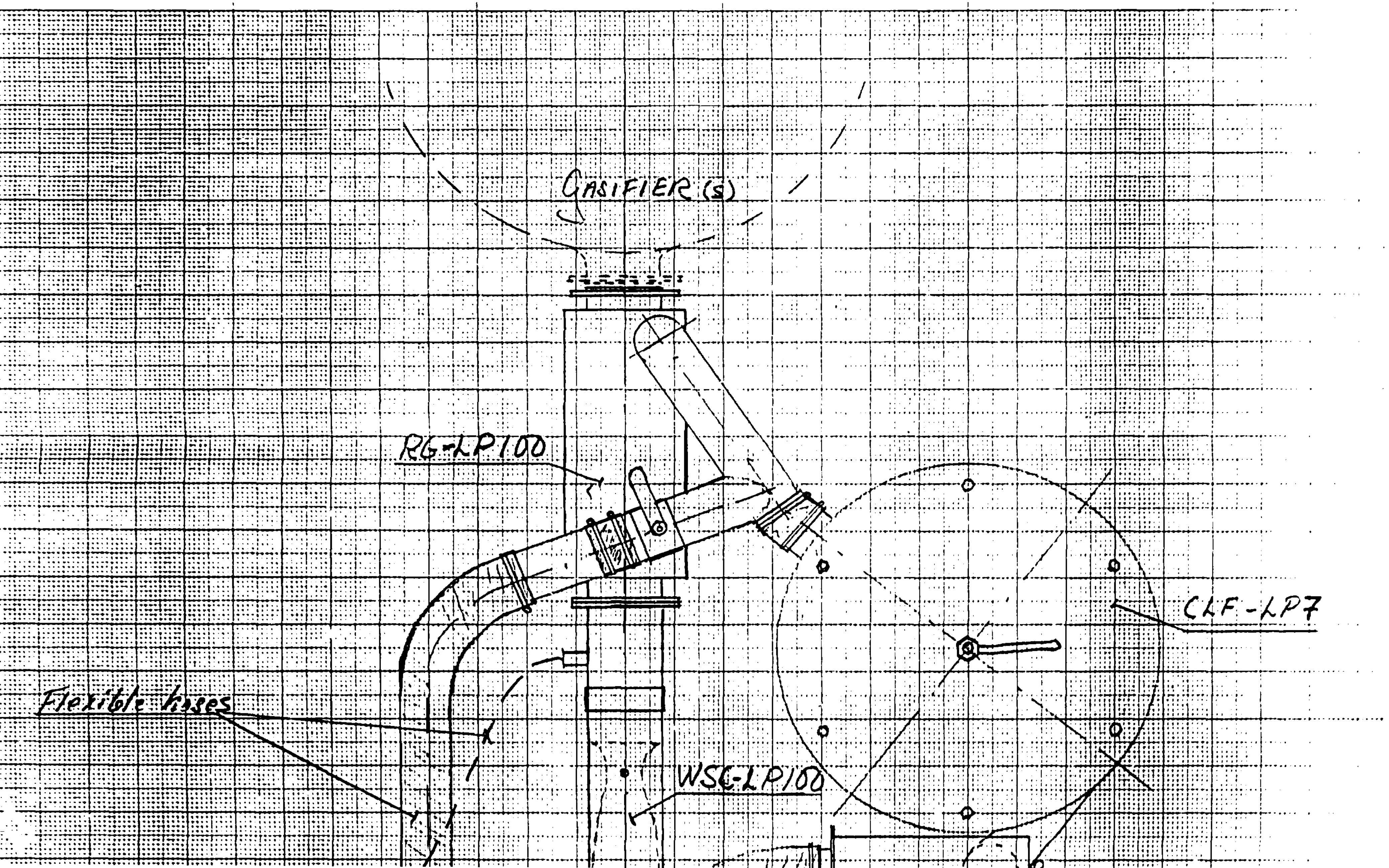
ANNEX J - EFFLUENT DESTRUCTION DEVICE





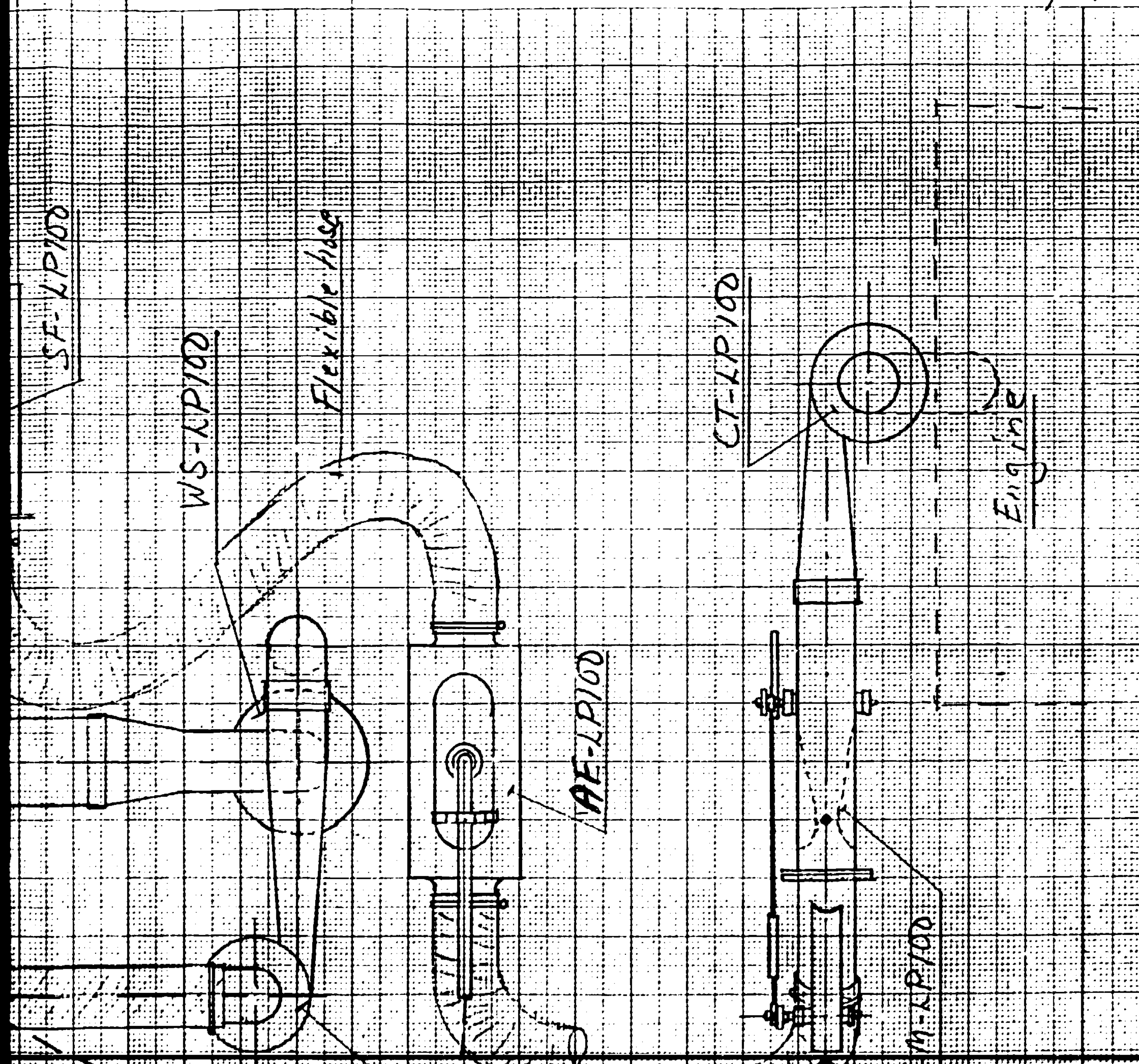


ANNEX K - DRAFT OF A PROPOSED MODIFICATION OF THE GAS CLEANING SYSTEM FOR THE ANKUR PLANT


GASIFIER (s)
RG-LP100
CLF-LP7
Flexible hoses
WSC-LP100

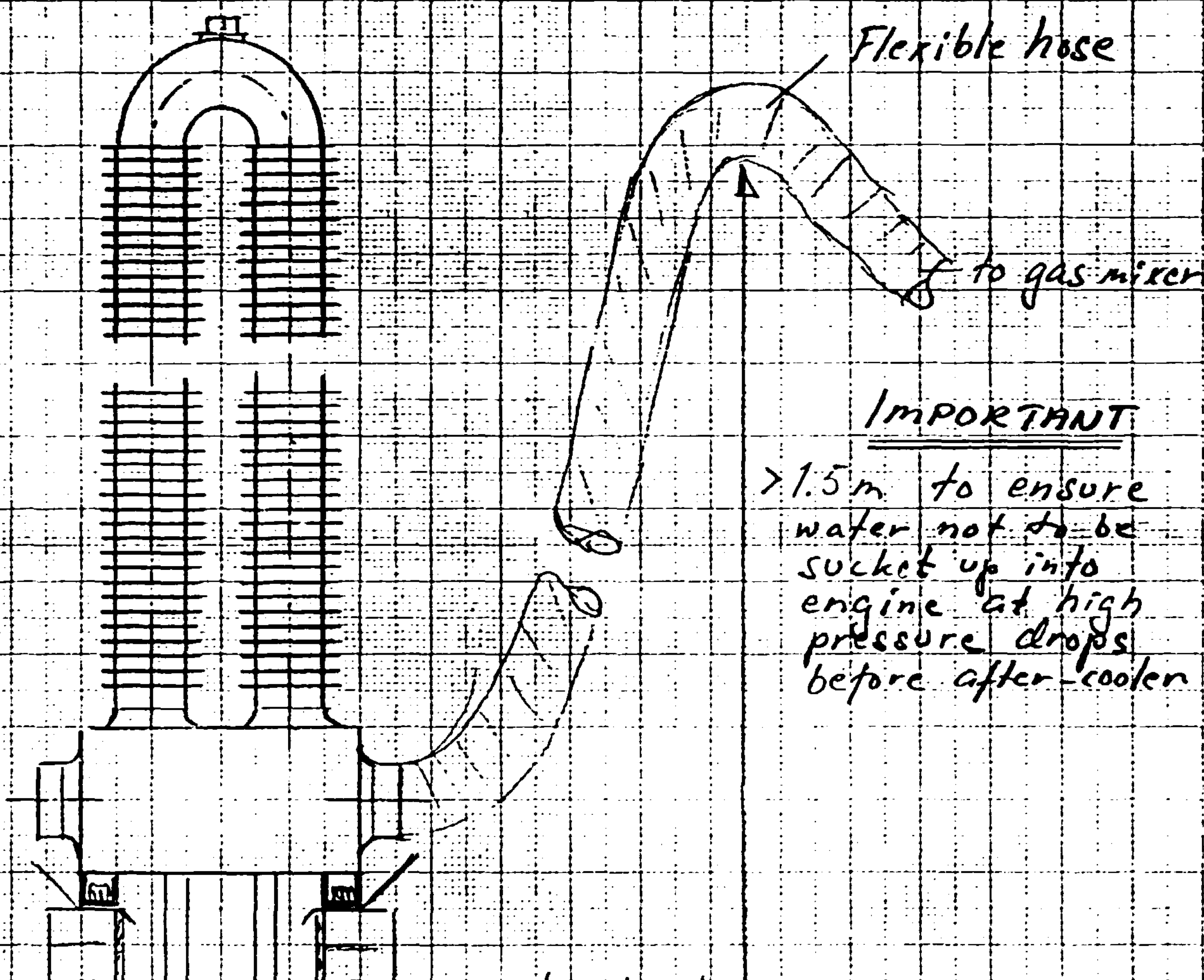
PRODUCER GAS COOLING/CLEA- PGCC-00
NING EQUIPMENT PGCC-LP100

8/5-91



AFTER-COOLER AFLP 100 AF-OD

26/4-91 LP

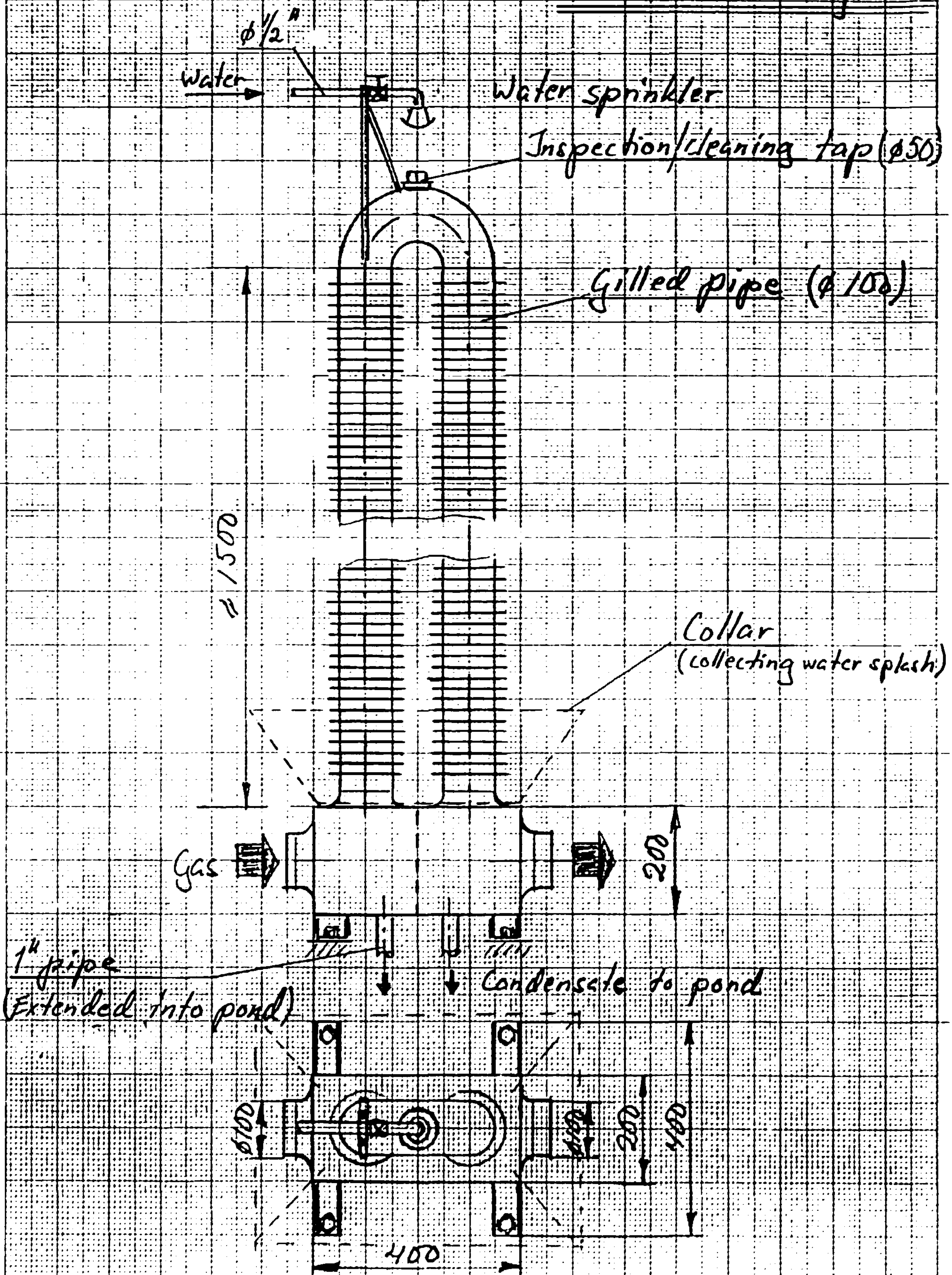


Note: All pipings to fit standard (available) pipes & hoses

After-cooler AF LP 100 AF-01

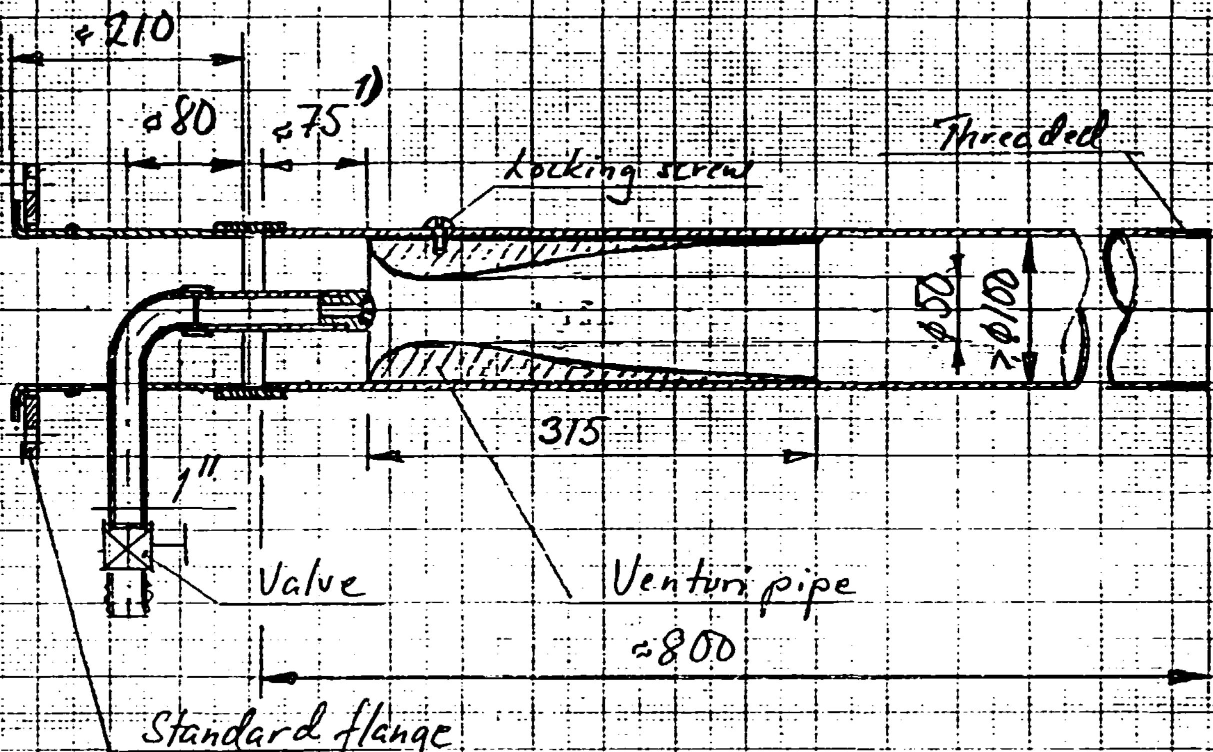
28/4-91

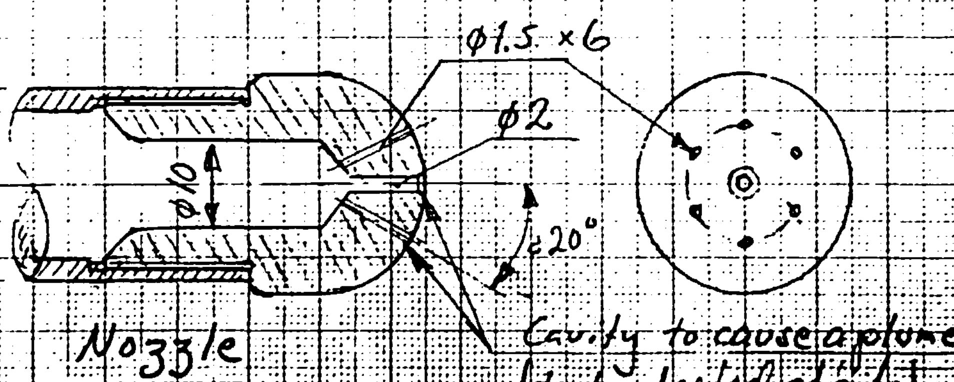
Please see drawing AF-01



Water scrubber WSLP 100 WS-01

17/7-91



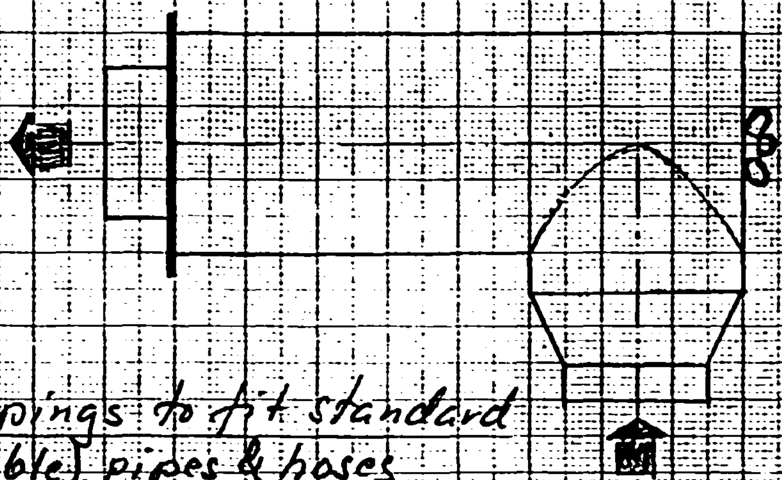


All dimensions following standard pipes

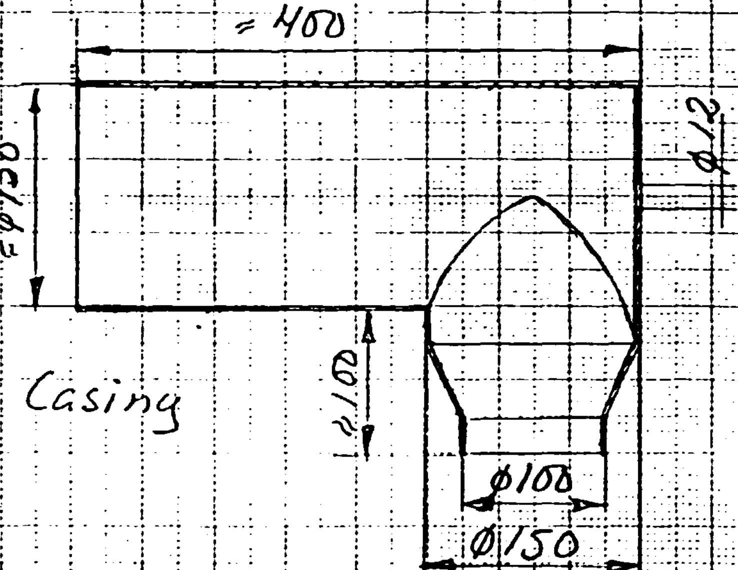
1) Position for optimum to be established practically

SAFETY FILTER SF2P 100 SF-00

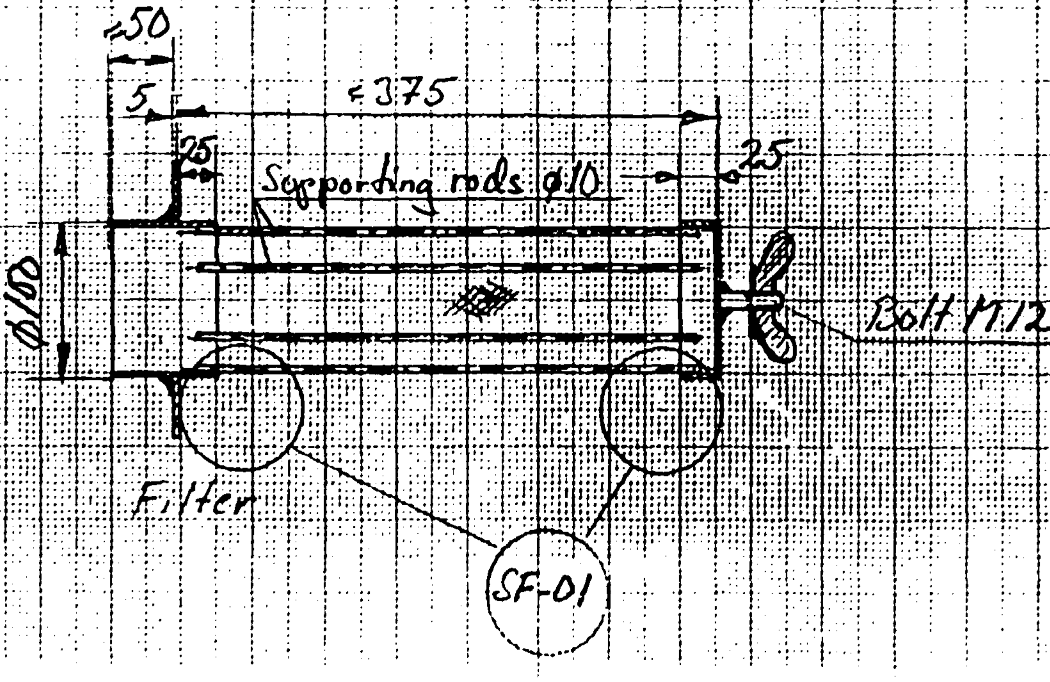
28/4-91



Note:
All pipings to fit standard (available) pipes & hoses



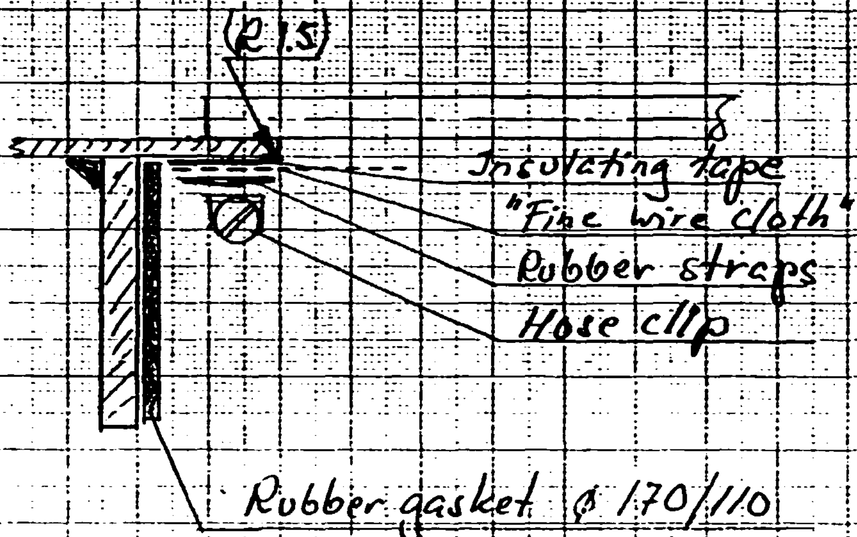
Casing

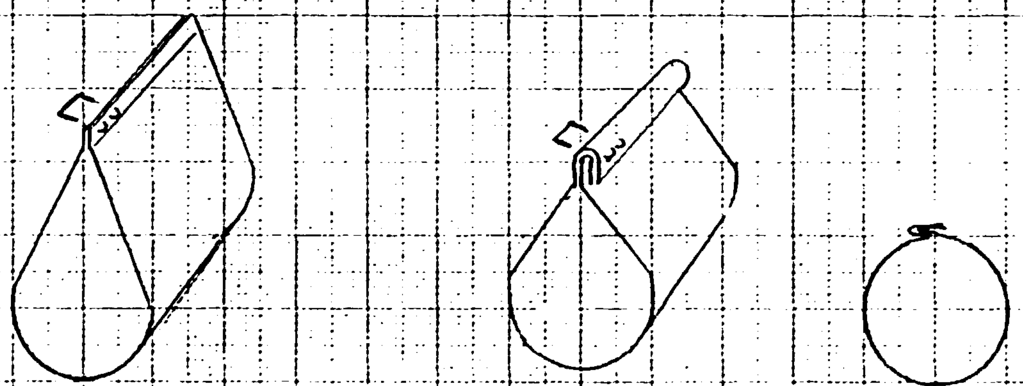


Filter

Safety Filter SF LP 100 SF-01

25/4-91

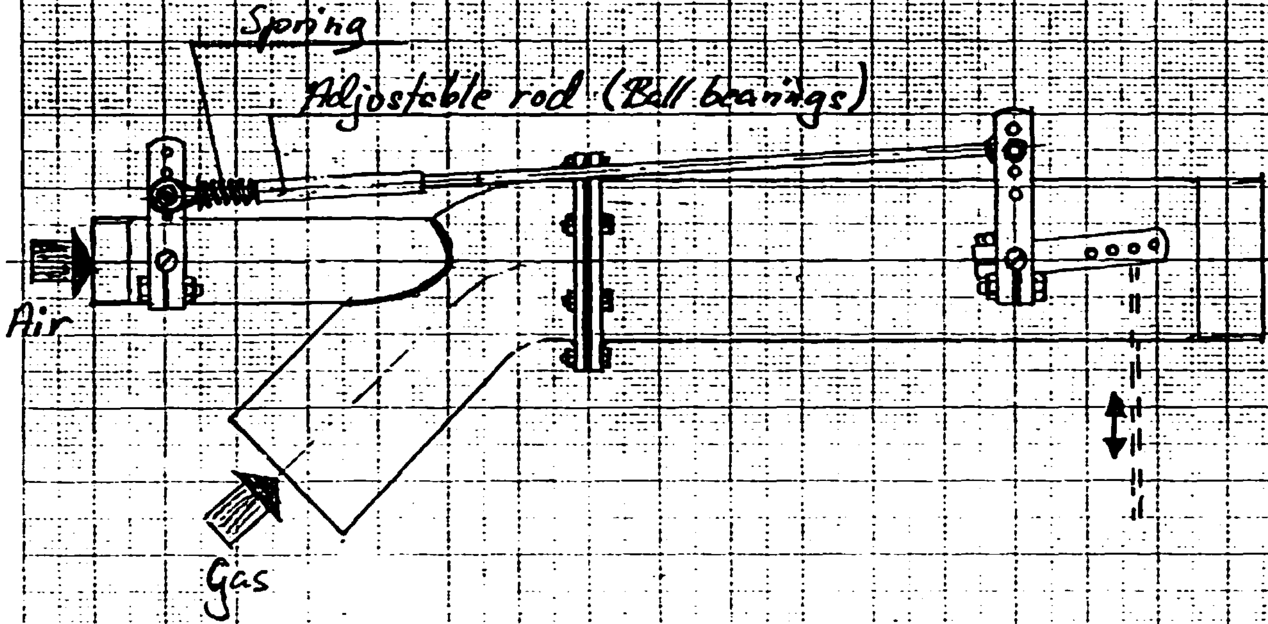


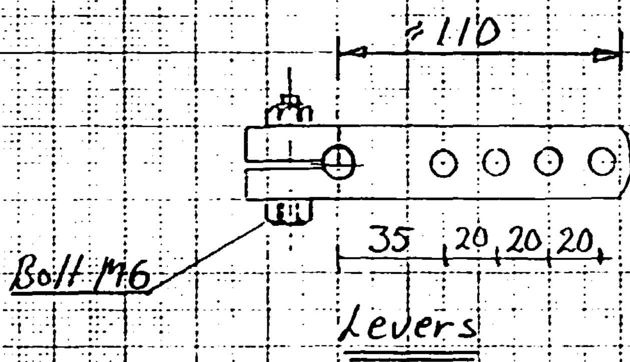


Folding of the wire cloth
(with an office stapler)

GAS MIXER GMLP 100 GM-00

22/4-91RP



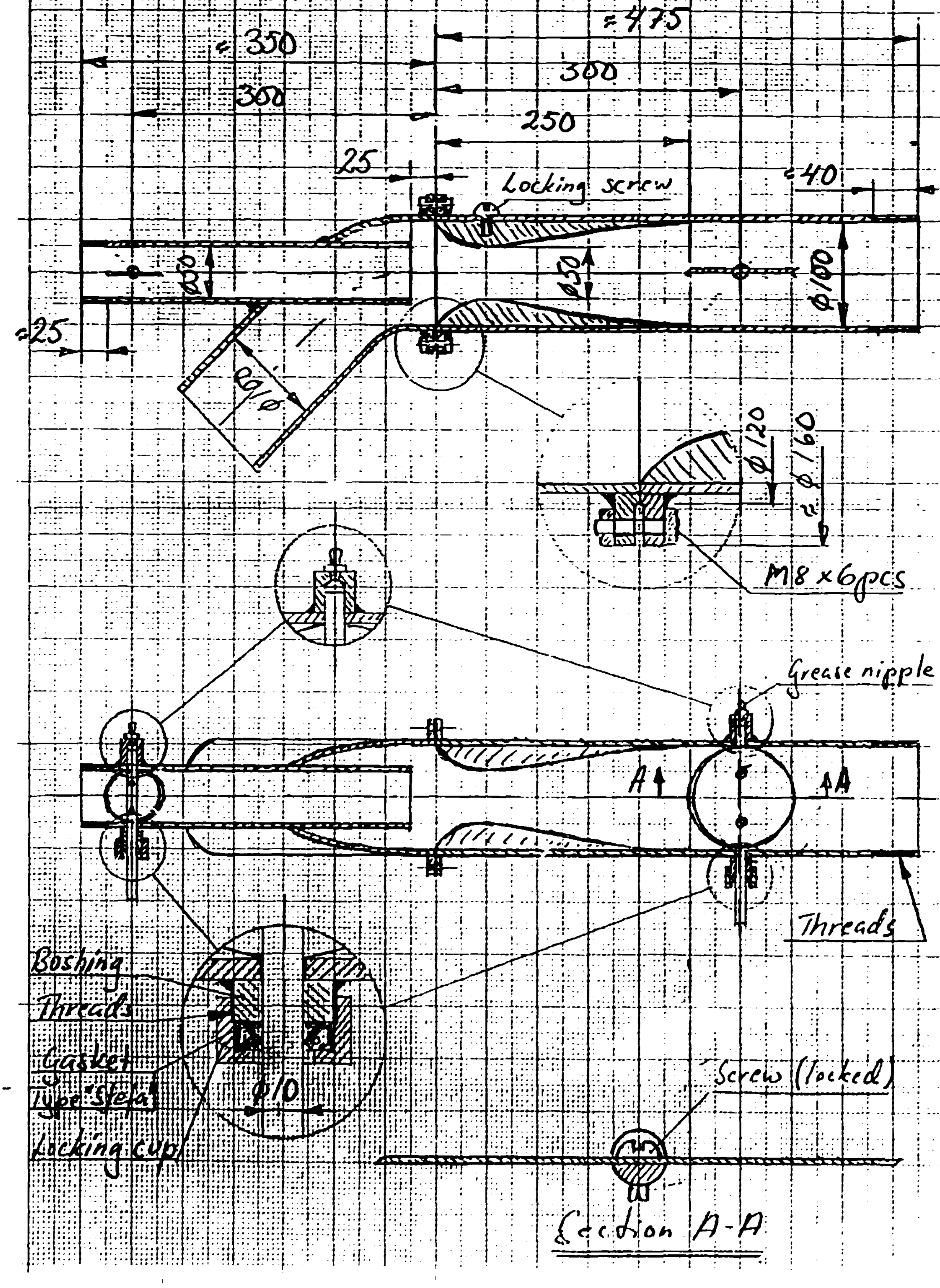


Note: Dimension to be choosen to fit standard (available) mashine parts

Gas mixer GMLP100 GM-01

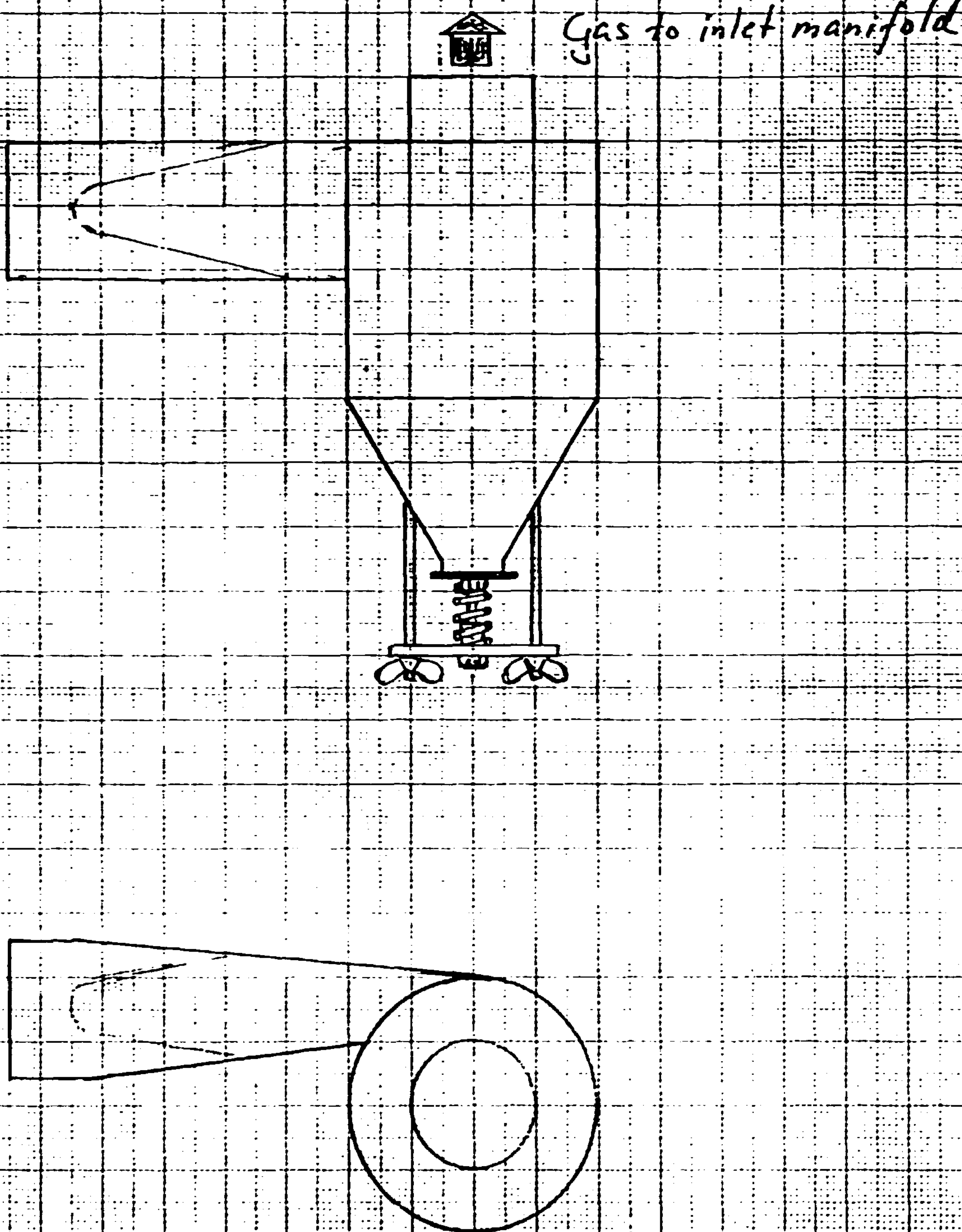
SP 22/4-91

Note: Valves & Venturi made to fit standard pipes



CONDENSATE TRAP CTLP 100 CT-00

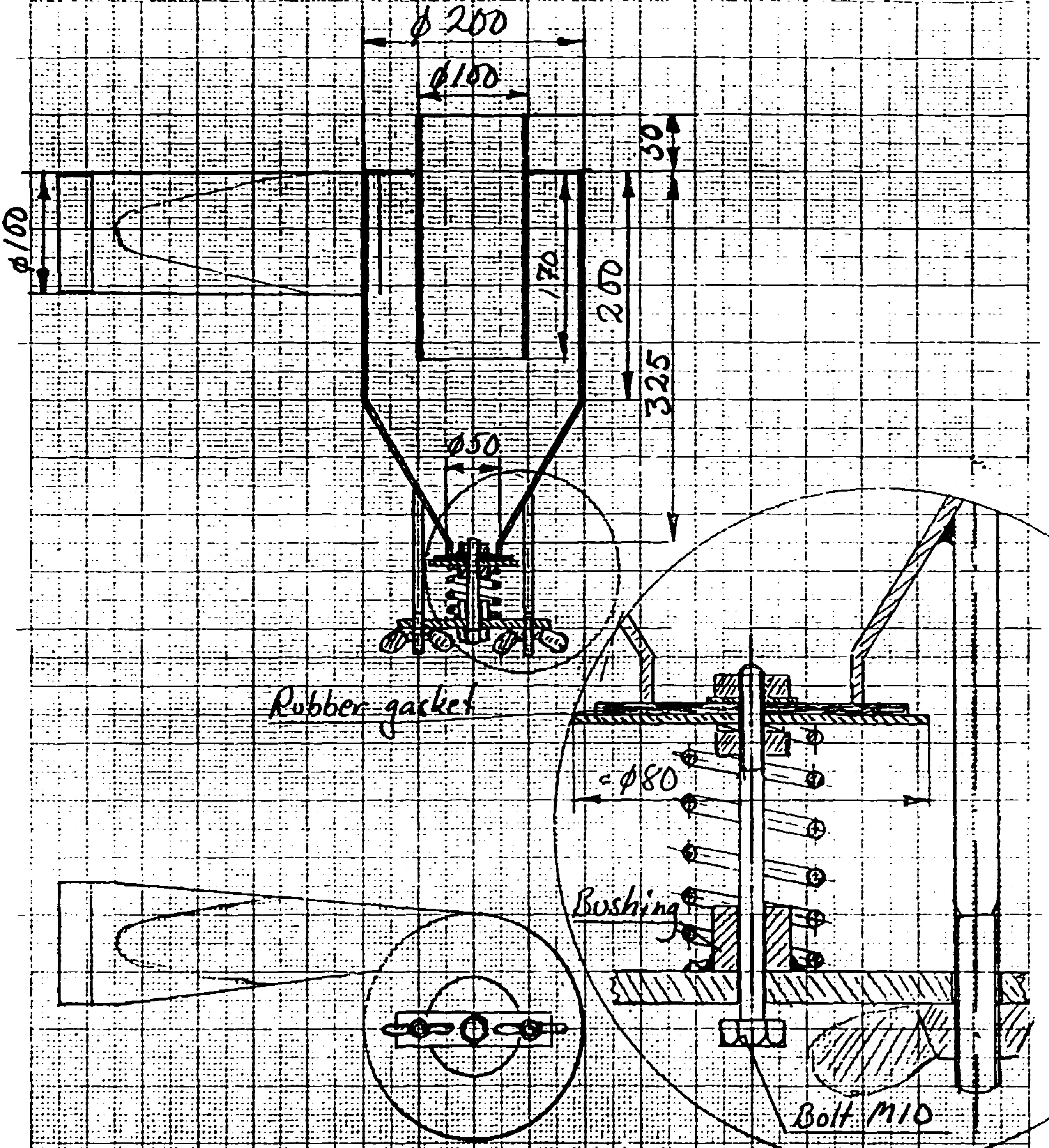
Equipped with explosion lid 22/4-91 LP



Note: Dimension to be choosen to fit standard (available) mashine parts

Condensate trap CTLP 100 CT-01

22/4-91

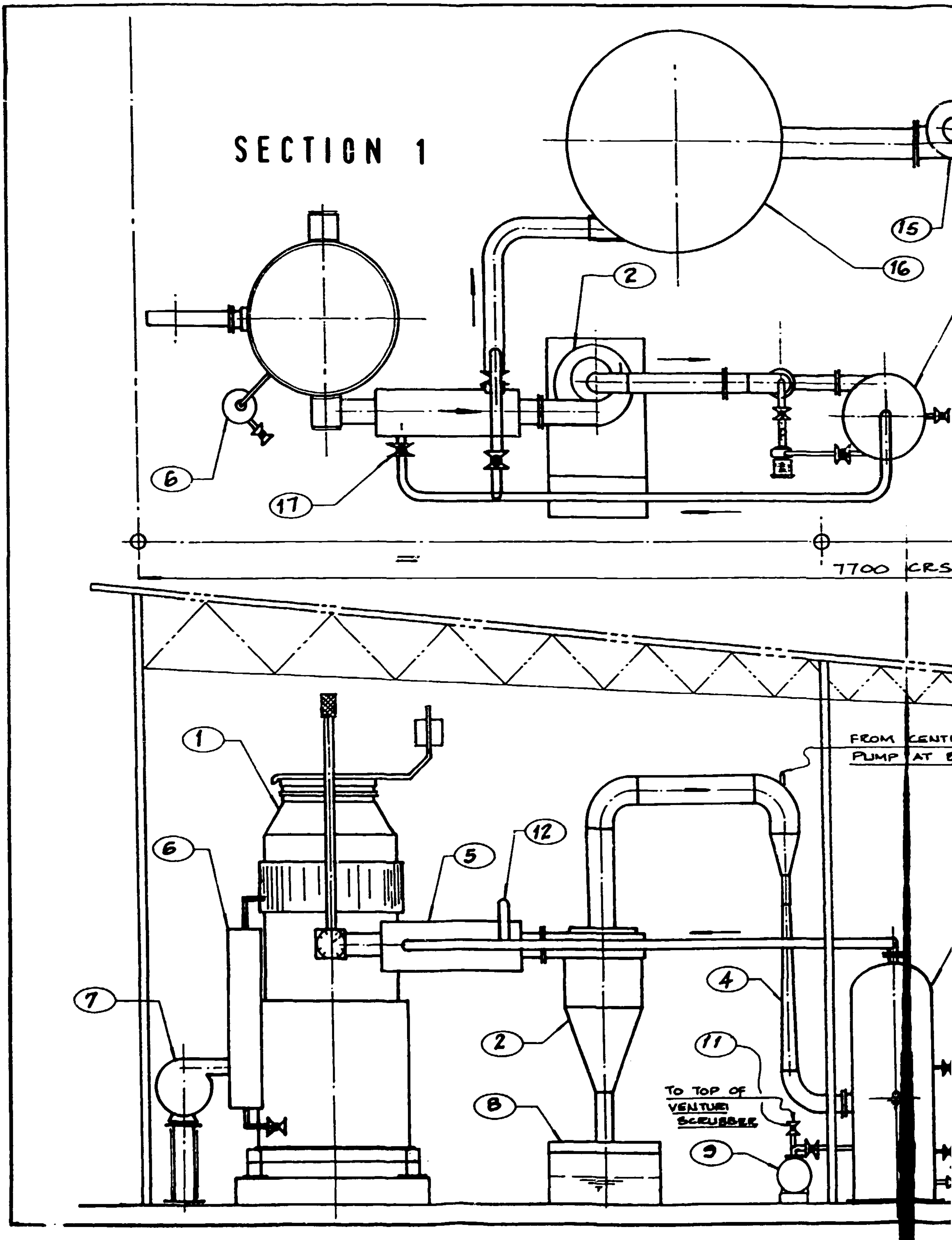


(Measures of detailes not important)

ANNEX L - TECHNICAL INFORMATION ON FINAL PROPOSAL

This annex contains drawings and sketches from the Sub–contractor's Final Report to UNIDO /12/

SECTION 1



15
16
2
6
17
7700 CRS
FROM CENT
PUMP AT
1
12
6
5
7
4
2
11
TO TOP OF
VENTURI
SCRUBBER
8
9

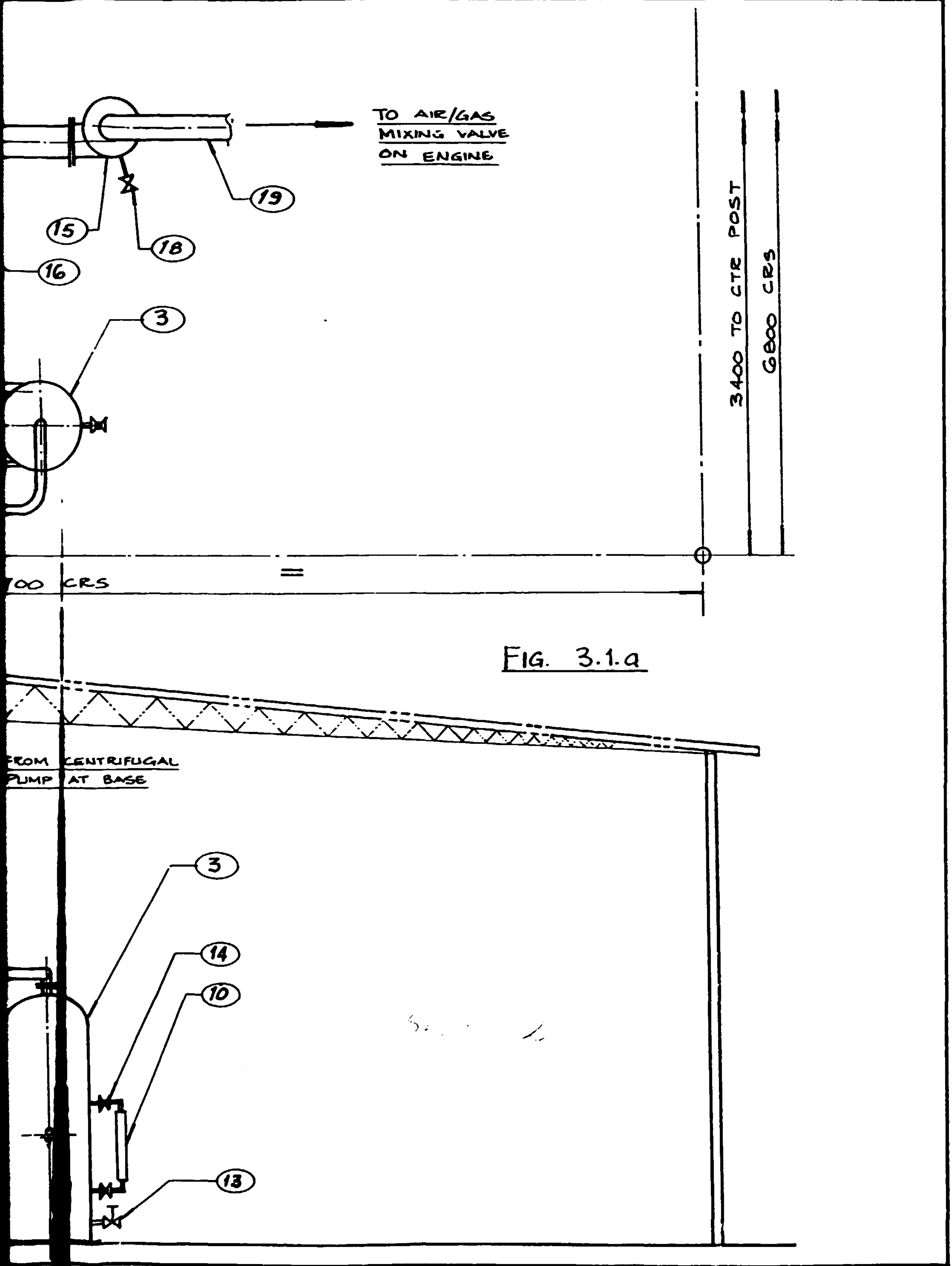
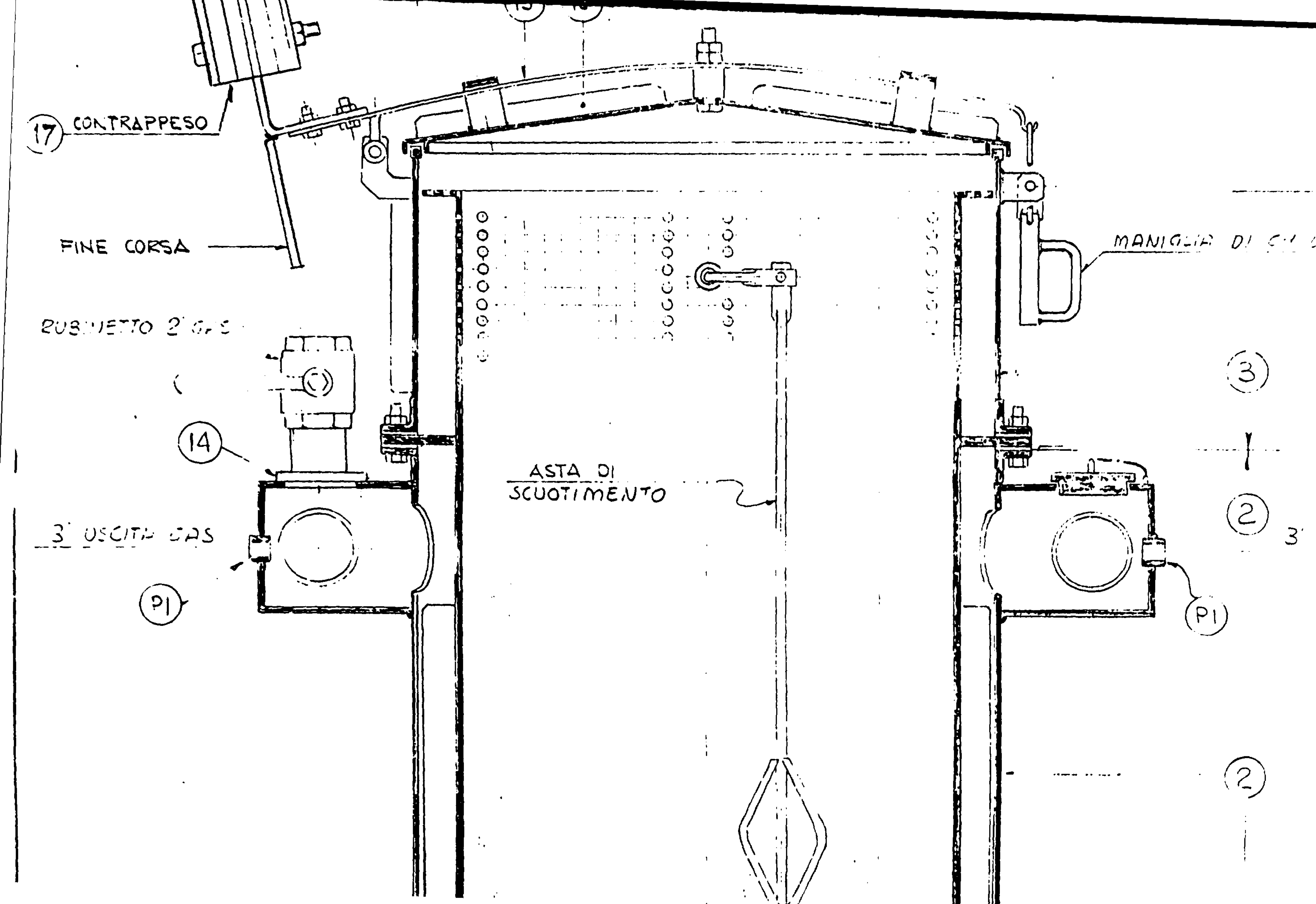
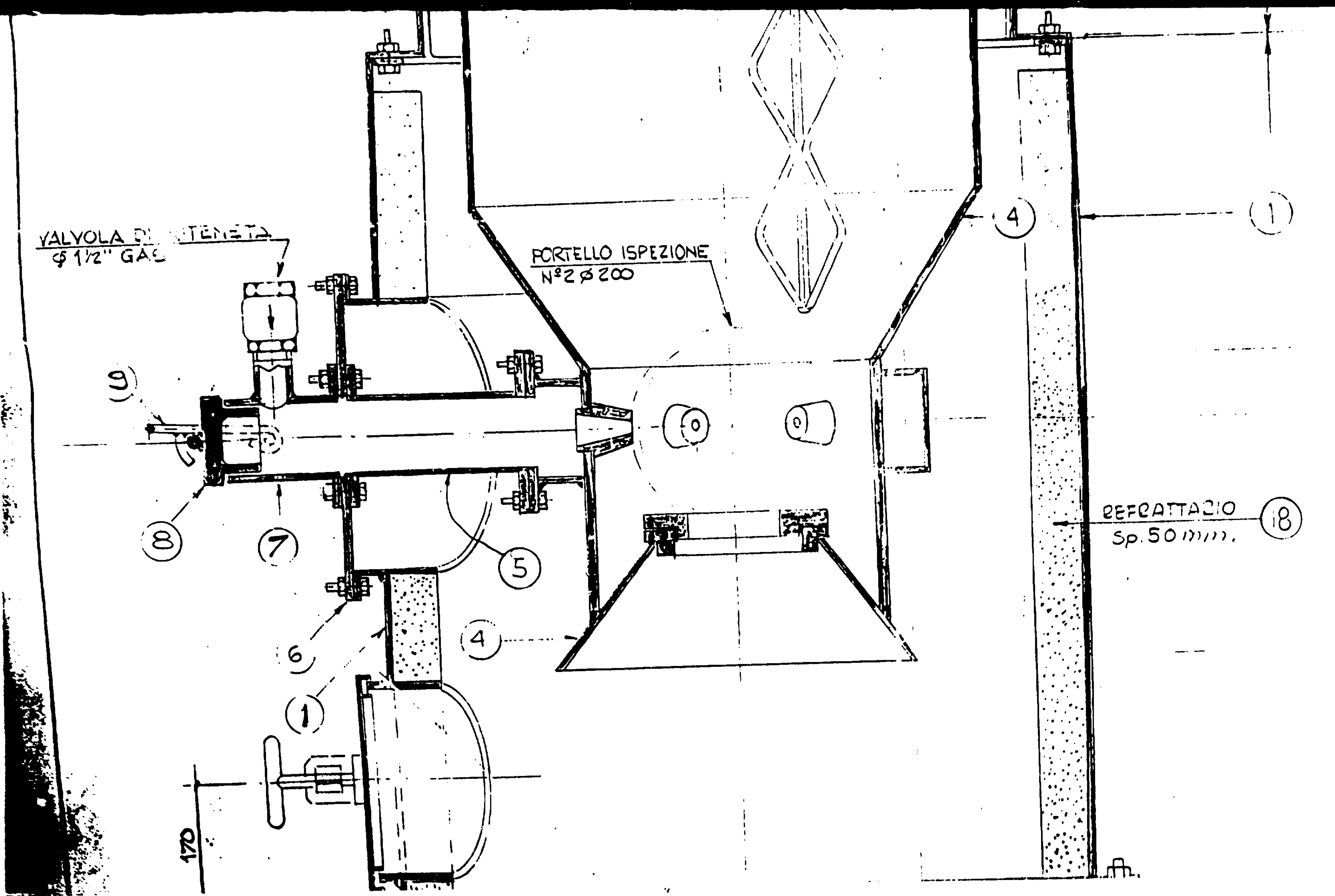
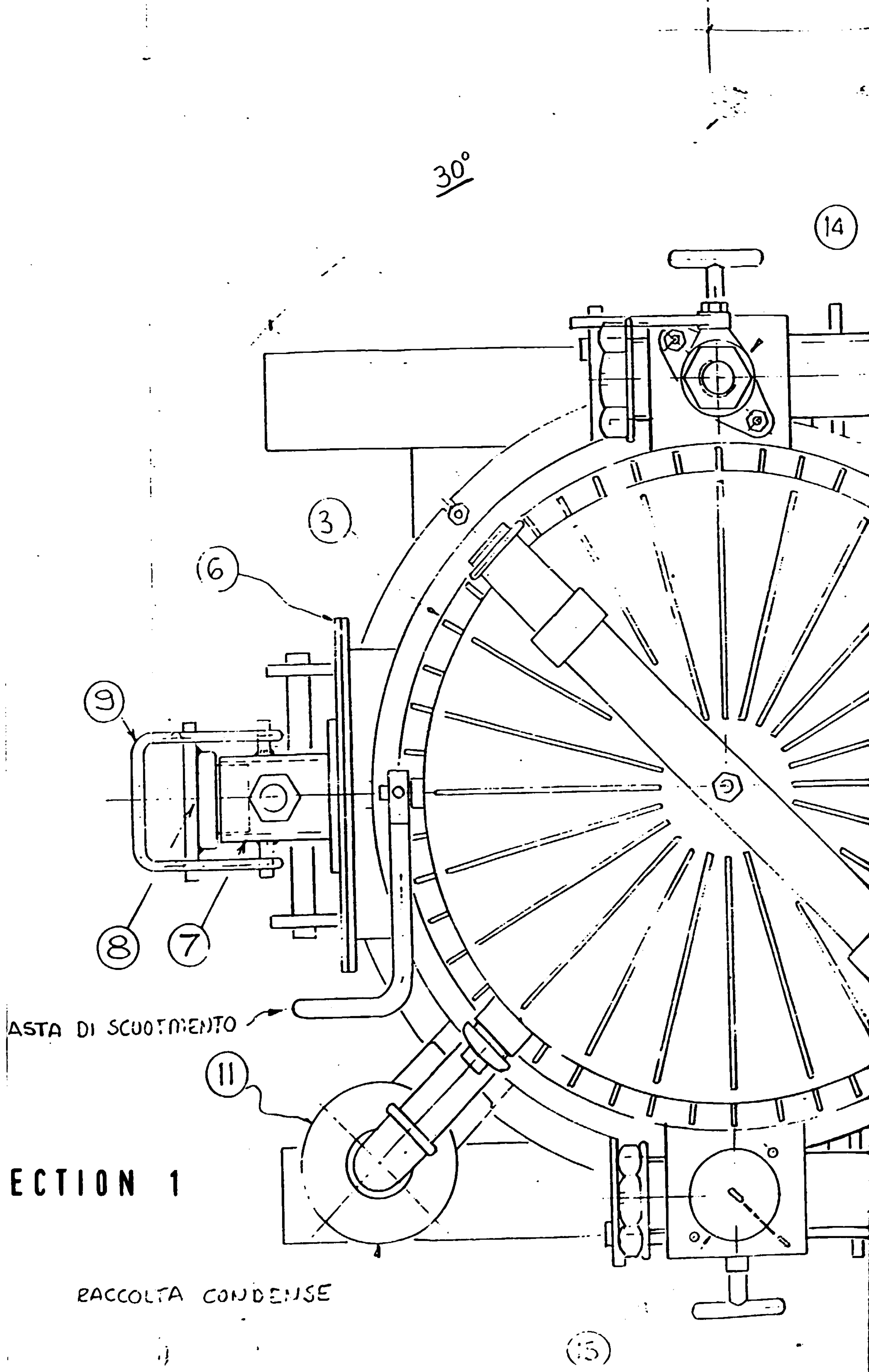

TO AIR/GAS
MIXING VALVE
ON ENGINE
19
15
18
16
3
3400 TO CTR POST
6800 CRS
=
700 CRS
FROM CENTRIFUGAL
PUMP AT BASE
3
14
10
13

FIG. 3.1.a

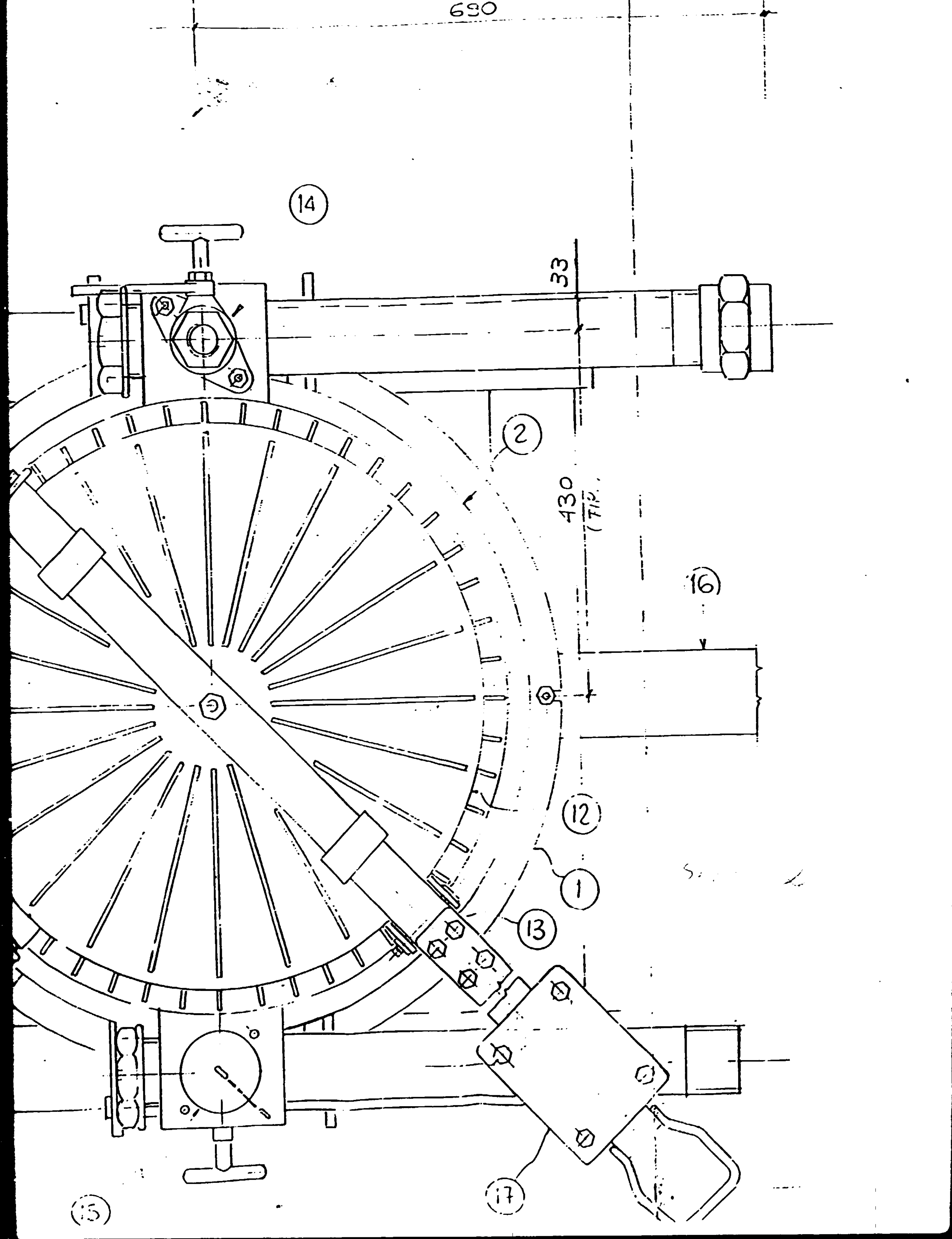
PRT NO	DESCRIPTION
27	
26	
25	
24	
23	
22	
21	
20	
19	FLEXIBLE HOSE TO AIR/GAS MIXING VALVE AND ENGINE.
18	DRAIN VALVE
17	CONTROL VALVE
16	FINAL FILTER
15	SAFETY VALVE
14	GAUGE GLASS VALVES
13	DRAIN VALVE (BLEED)
12	BY-PASS LINE
11	FEED CONTROL VALVES
10	GAUGE GLASS
9	CENTRIFUGAL PUMP
8	DE-ASHING TROUGH
7	AIR BLAST FAN
6	CONDENSER
5	HEAT EXCHANGER
4	VENTURI
3	SEPARATOR
2	MULTICYCLONE
1	REACTOR (GENERATOR)


17 CONTRAPPESO
FINE CORSA
14
3' USCITA GAS
P1
ASTA DI
SCUOTIMENTO
3
2
3'
P1
2

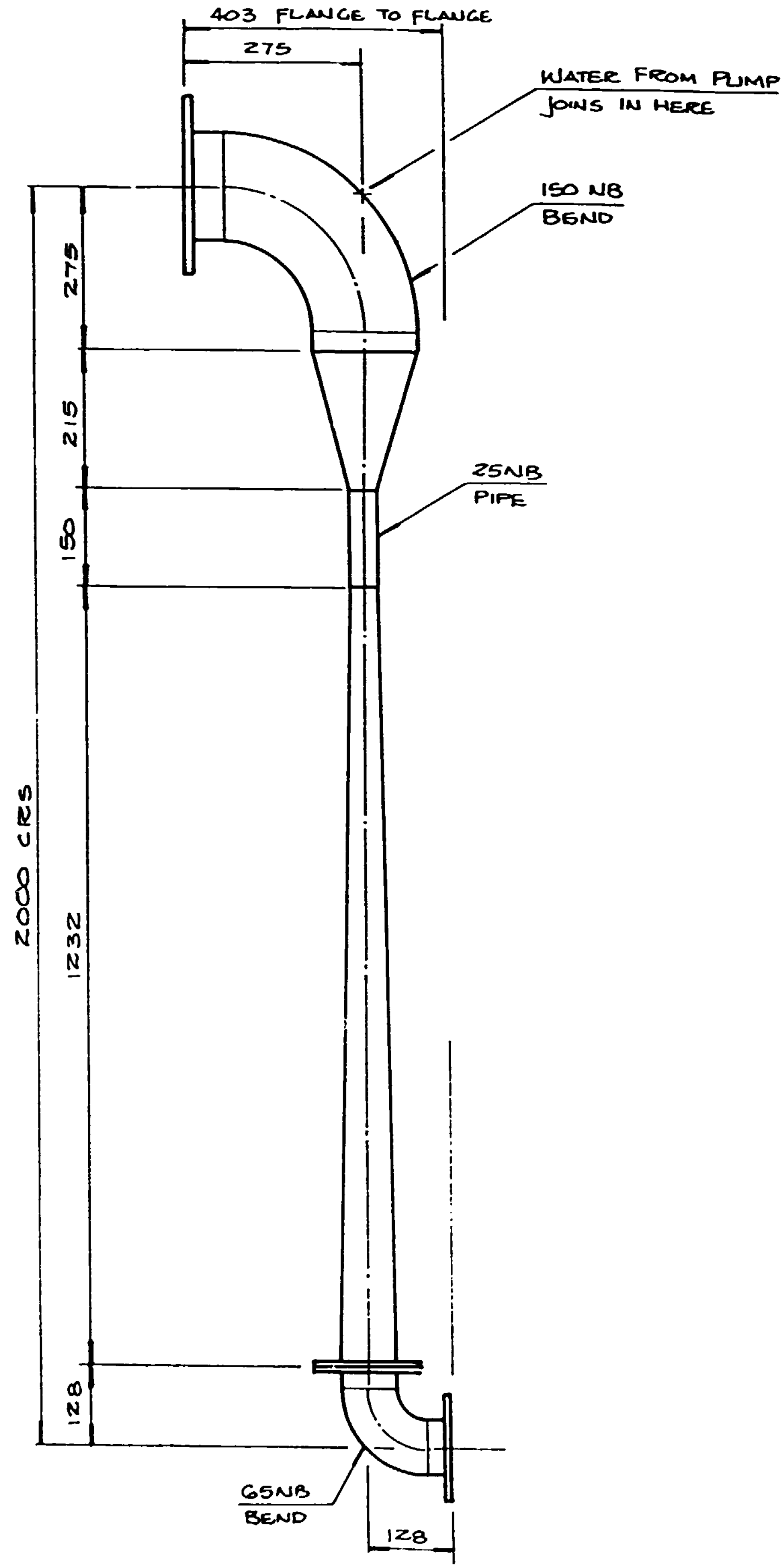

VALVOLA DI TENUTA
ϕ 1½" GAS
PORTELLO ISPEZIONE
N°2 ϕ 200
REFRATTARIO
Sp. 50 mm.
1
4
18
9
8
7
5
6
4
1
170



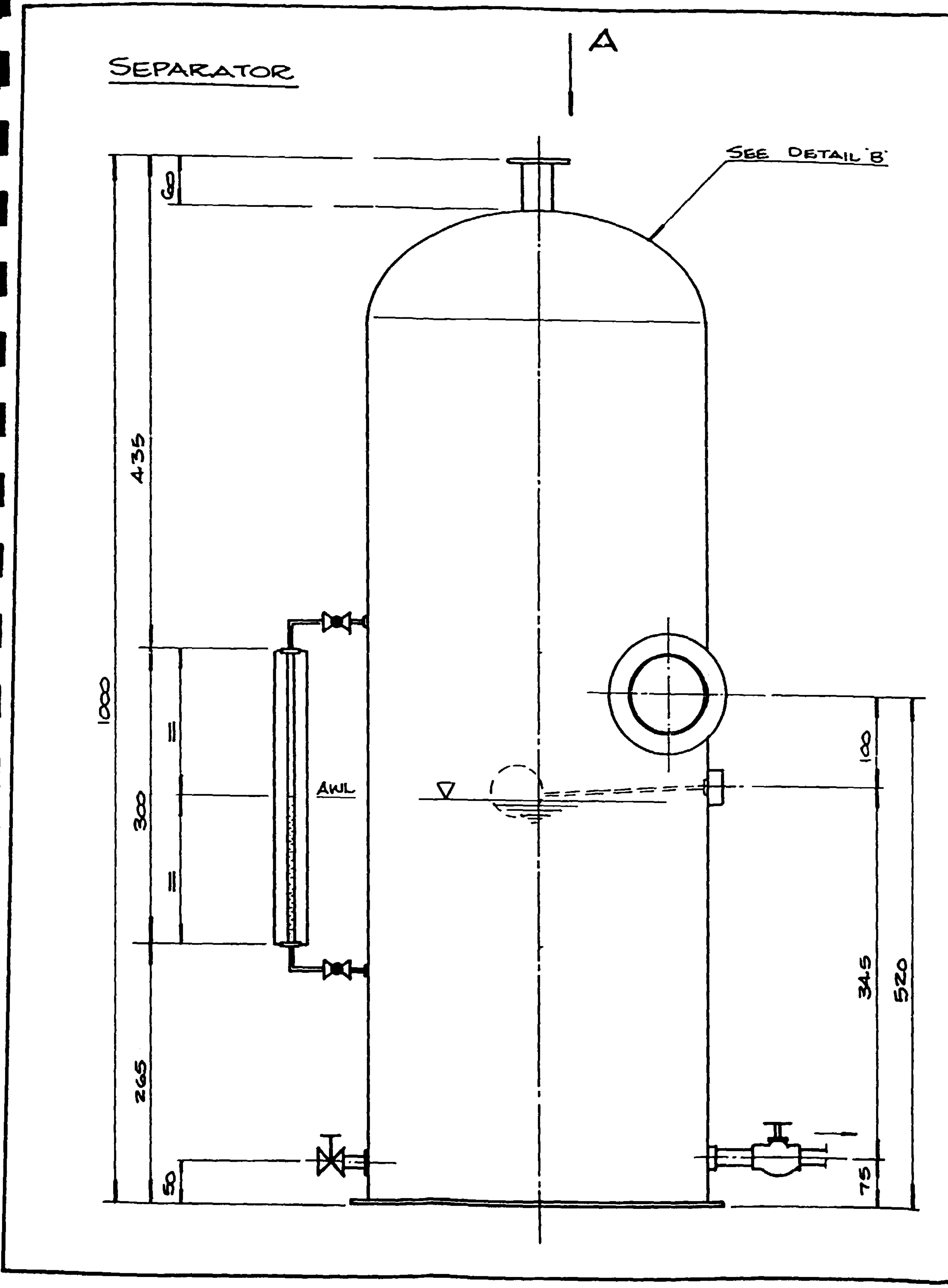
SECTION 1



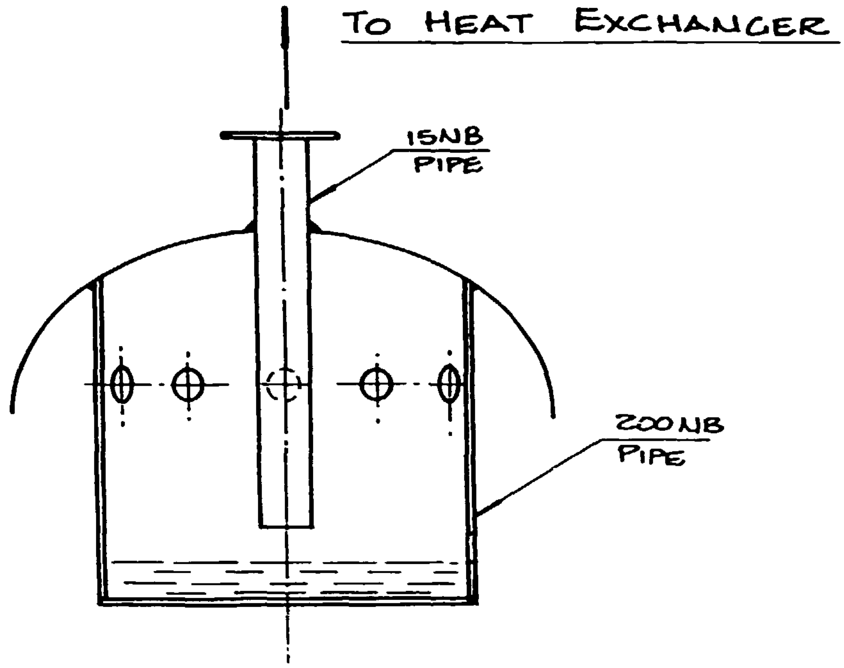
690
14
33
2
430
(TIP.
16
12
1
13
17
15



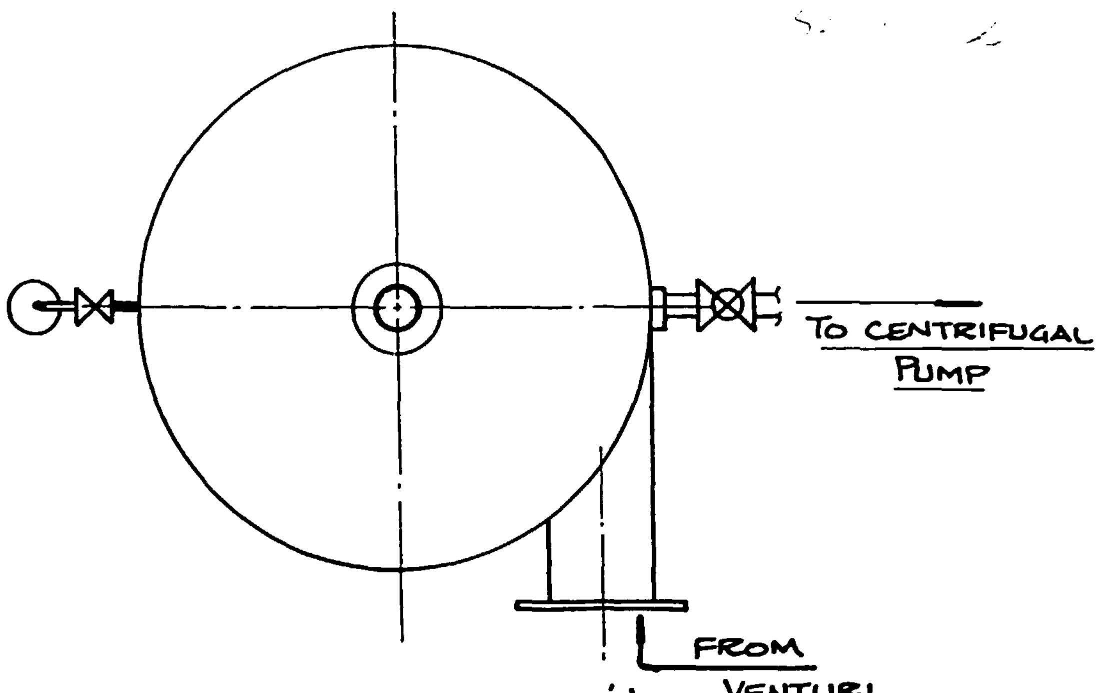
VENTURI SCRUBBER


SEPARATOR
A
SEE DETAIL 'B'
60
435
1000
300
AWL
265
50
100
345
520
75

SECTION 1

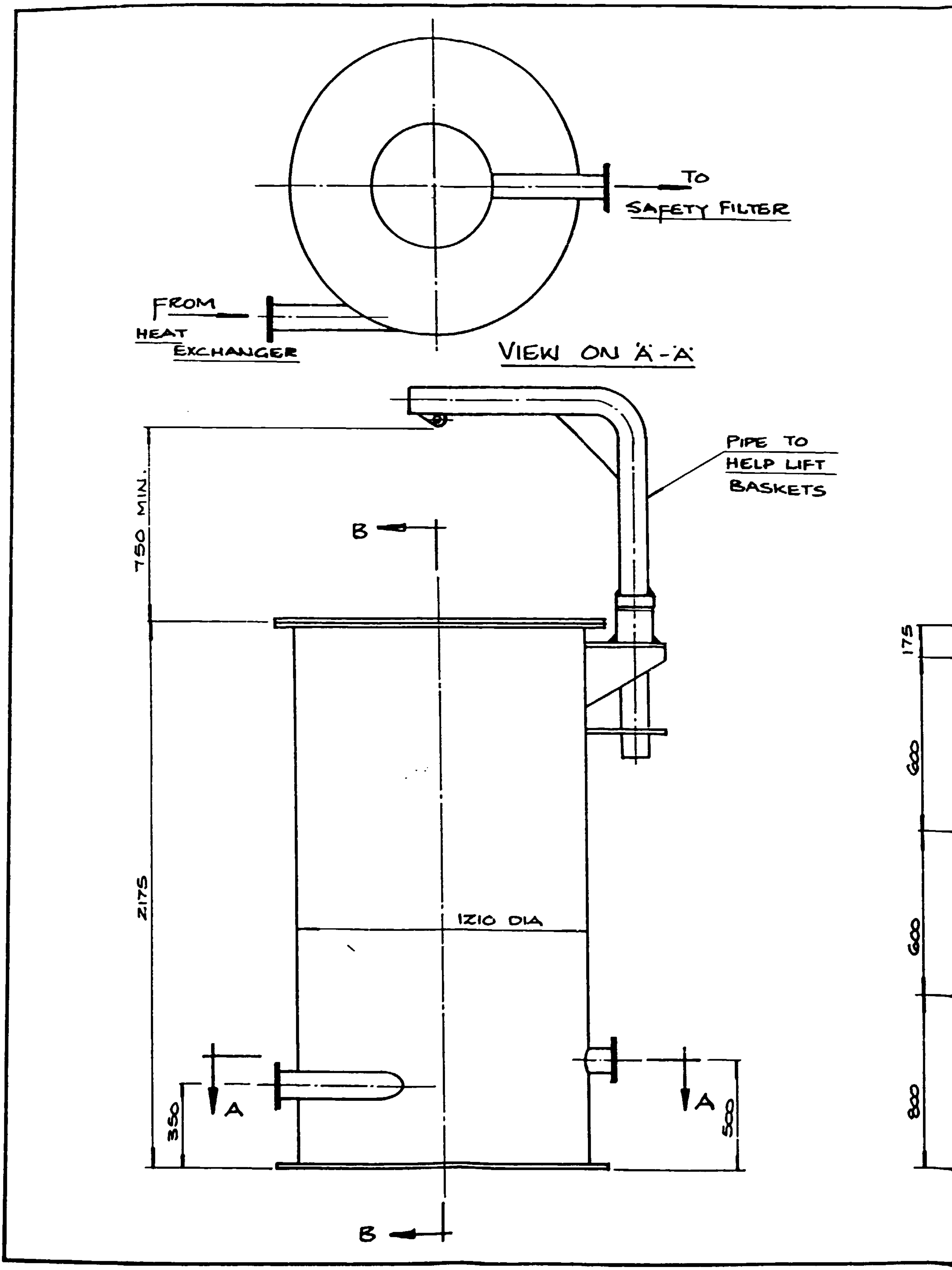


DETAIL 'B'

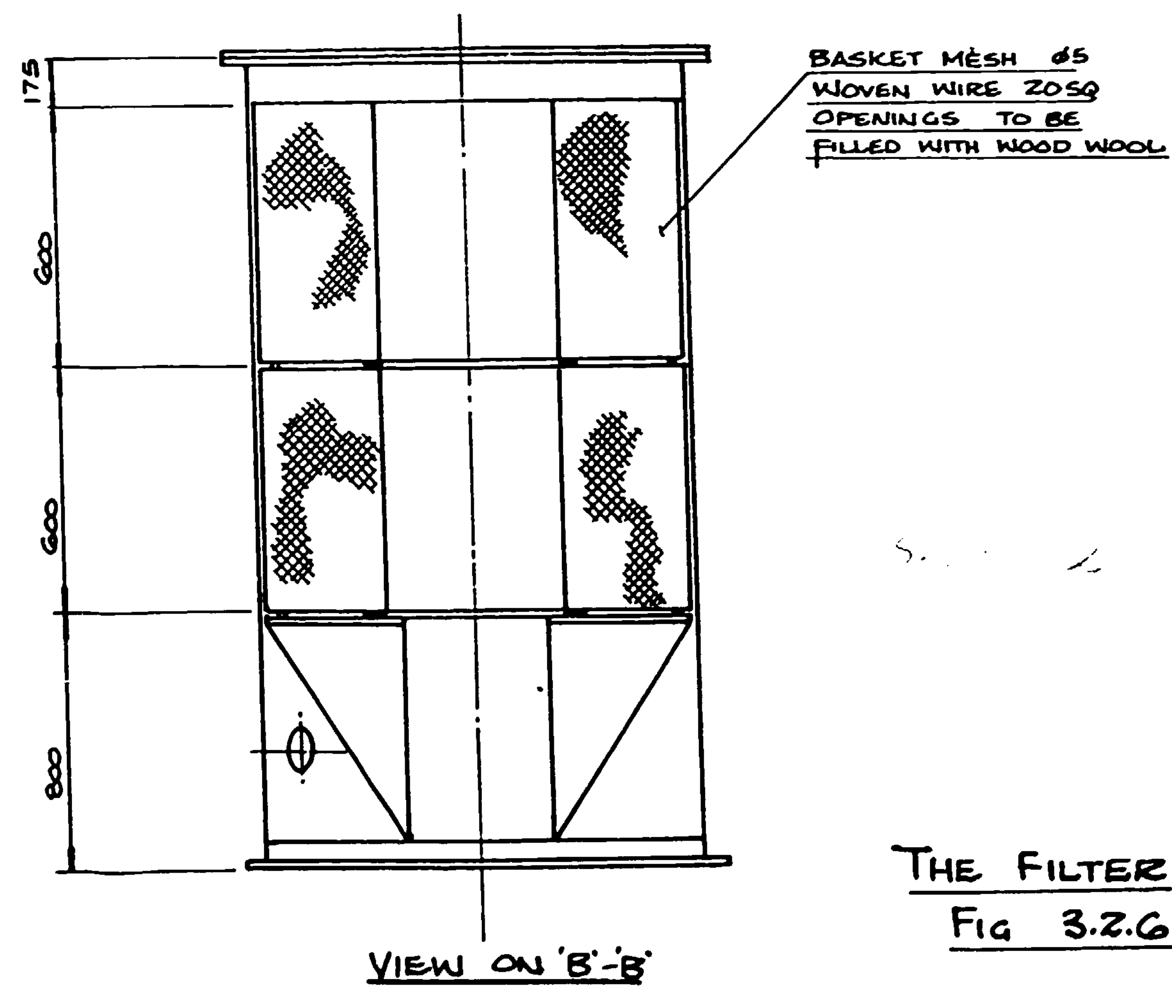


VIEW ON ARROW 'A'

THE SEPARATOR FIG 3.2.5.a


TO
SAFETY FILTER
FROM
HEAT
EXCHANGER
VIEW ON A-A
PIPE TO
HELP LIFT
BASKETS
750 MIN.
B
2175
1210 DIA
A
350
A
500
B
175
600
600
800

SECTION 1



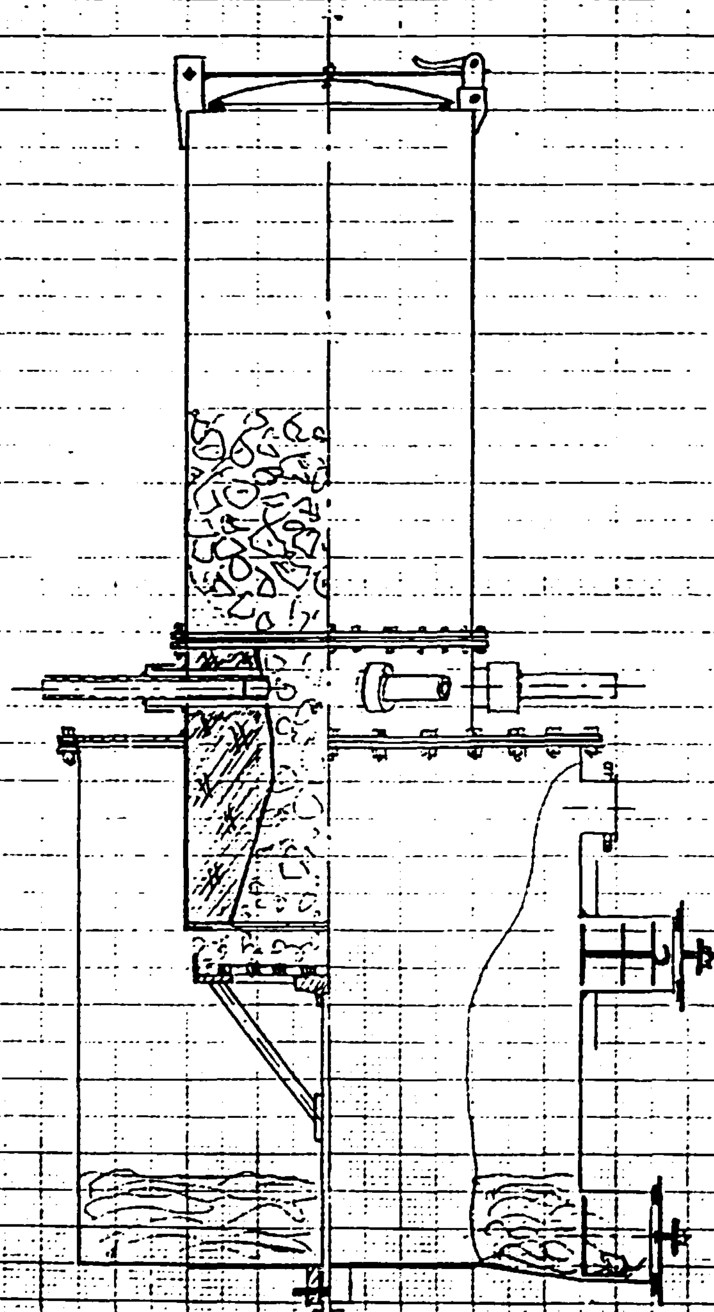
THE FILTER

FIG 3.2.6.a

ANNEX M - SKETCH ON A CHARCOAL GAS PRODUCER OF SIMPLE DESIGN

GASIFIER GP-6

ZP



ANNEX N - EXAMPLES ON DAILY OPERATING REPORT

DAILY OPERATING REPORT

Gasifier system: S.E.S Load[1]: ~~PUMP~~/DRYERS Date: 28/10/91 Operator: Munyanyi

Checks and service made before operation:

Oil level in engine[2] ✓ ... Oil added liter ...X... Engine oil changed[3] ...X... Engine oil sample number[4] ...5... Charcoal bed level in gasifier[2] ✓ ..... Charcoal added kg ...34...

Water level in scrubber[2] ✓..... Ashes removed from gasifier[2] ✓...... Condensates drained: Gasifier and scrubber liter[5] ✓...... Baffle filter[2] ✓.....

Filters cleaned: Cyclone filter[2] ✓...... Scrubber[2] ✓..... ~~Baffle~~ Cake filter[2] ✓...... Day filter[2] ✓... safety (air blower)

Preparation time minutes ...1½ hrs...

Comments: Empty-19, Blast strip, Disc safety, g/a mixer } done 26/10

Observations during start-up:

Time from ignition to operation on load, minutes ...15........ , Smoke from sealings during fan operation[1] yes/no

Summary of daily input and output:

	Before start	After shutdown	Difference	
Accumulated operating hours	885.61	900.95	15.34	(Operating hours for the day)
Accumulated kWh	5764.4	6228.8	264.4	(kWh generated during the day)

Fuel consumption:

Fuel type: ...Cobs... Fuel moisture content %[6] .... Total amount used kg[7] ...358.08

Specific fuel consumption dry kg/kWh[8] ...1.4...

Comments: 894.51 hrs - engine end, power loss, changed safety filter, cleaned g/a mixer, drained condensate and scrubber, then reconnected; again at 900.61 hrs power loss when ~~restarted~~ backfiring no load on EG & > 400°C. Safety [illegible] Δp > 120 mm. Ash in BG reactor (27.25 l total)

Gasifier system: S.E.S Load: Pump/Dryers Date: 25/10/91 Operator: Munyanyi

Time of day	Input Fuel type	Engine hrs	Output KWh-meter	R-phase V Volt	A Amp	System conditions Gasifier Gastemp Out °C	Gaspress Out	Scrubber Water temp °C	Final Filter Gaspress mm Out	Safety filter Gaspress mm In	Out	Mixer Gastemp °C
		885.2										
[illegible]:30	Ch	885.61	5964.4	410			70	31	190	280	280	25.9
08.00		886.18	5969.0	400	65	~~65~~	165	34	450	545	550	26.1
08.30		886.64	5980.0	390	64	64	130	38	470	570	560	27.9
09.00		887.12	5999.8	415	35		115	37	410	490	490	28.5
09.30		887.61	5998.5	410	34		115	36	440	545	555	29.7
10.00		888.13	6007.4	410	34		115	37	420	510	540	30.3
10.30		888.64	6016.2	400	34		130	37	450	535	530	30.7
11.00		889.13	6024.6	410	34		125	36	425	510	510	31.7
11.30		889.68	6034.0	400	55		145	36	460	590	595	32.4
2.00		890.12	6042.5	390	57		120	37	460	580	580	32.7
2.30		890.62	6051.2	400	32		115	38	450	560	570	32.3
3.00		891.16	6060.1	420	32		115	37	420	515	515	32.7
3.30		891.61	6067.8	410	32		117	36	416	508	508	3[illegible]
4.00		892.12	6076.7	410	32		129	36	421	534	538	32.8
4.30		892.64	6085.4	410	36		114	37	450	472	500	32.7
5.00		893.13	6093.4	39[illegible]	52		112	37	397	484	485	33.2

..LY OPERATING REPORT

Gasifier system: S.E.S   Load: ~~Pump~~/Dryers   Date: 28.10.91   Operator: Wakatama

Time of day	Input Fuel type	Engine ~~kg~~ hrs	Output KWh-meter	R-phase V Volt	R-phase A Amp	System conditions Gasifier Gastemp Out °C	Gaspress Out	Scrubber Water temp °C	Final Filter Gaspress mm Out	Safety filter Gaspress mm In	Safety filter Gaspress mm Out	Mixer Gastemp °C
15.30		893.61	6101.0	400	34		115	38	420	520	520	32.6
16.00		894.14	6110.9	410	32		121	37	469	549	558	31.8
16.30		894.51	6117.1 →	< 380	< 45							
17.00		~~89~~										
17.30		894.91	6121.7	425	35		195	34	524	620	622	30.5
18.00		895.42	6132.1	425	35		180	38	513	582	582	29.4
18.30		895.92	6141.9	425	35		160	39	490	577	595	28.7
19.00		896.40	6150.3	420	35		158	38	460	550	565	28.5
19.30		896.91	6159.8	420	35		148	38	438	515	518	27.9
20.00		897.42	6169.1	415	35		210	37	440	510	515	27.3
20.30		897.91	6175.4	415	35		135	35	430	475	490	27.0
21.00		898.43	6188.1	415	37		162	35	~~520~~ 455	520	525	26.4
21.30		898.93	6197.2	410	36		145	37	425	500	500	25.8
22.00		899.42	6206.1	415	37		165	36	455	530	540	25.4
22.30		899.90	6215.0	420	~~36~~ 38		160	36	445	505	765	24.9
23.00		900.43	6224.9	420	35		145	34	400	460	1200	24.4
		[illegible]	[illegible]									

DAILY OPERATING REPORT

Gasifier system: ANKUR   Load[1]: PUMP/DRYERS   Date: 18.11.91...   Operator: Kapurtipur

Checks and service made before operation:

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

Water level scrubber pond[2] ✓....   Ashes removed: from gasifier pond[2] ✓......   from cyclone[2] ✓.......   Filters cleaned: Scrubber[2] ✓........   wood/metal Fabric filter[2] ✓.........   hdie ~~Dry~~ filter[2] ✓.........

Preparation time minutes .125.......   Comments: Emptying filters...

Observations during start-up:

Time from ignition to operation on load, minutes ..12..........   Smoke from sealings during fan operation[1] yes/no

Summary of daily input and output:

	Before start	After shutdown	Difference	
Accumulated operating hours	670.2	682.9	12.7	(Operating hours for the day)
Accumulated kWh	....	....	....	(kWh generated during the day)
Diesel level in tank, cm	3	4	....	

Net consumption from tank: ......39........ liter   Diesel added to tank: ......40........ liter   Diesel consumed during day: .... liter

Fuel consumption:

Fuel type: ...coke.................   Fuel moisture content %[5] ....   Total amount used kg[6] .242.68..

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

Comments: Total hrs run 12.7hrs but 6.7 hrs not on load.
Plenty of water in the safety filter

DAILY OPERATING REPORT

Gasifier system: Ankur Load: Pump/Dryers Date: 18.11.91 Operator: S. Kapurtipati

Time Of Day	Input Fuel Type	fuel Kg	Output R- Phase V Volt	A Amp	SYSTEM CONDITIONS Separator Box Gastemp In (separator)	Gaspress Out	Fabric Filter Gaspress Out (final filter)	Safety filter Gaspress In	Out	Engine Gastemp °C	Diesel Time
09 45		670,2									
10.15		670,5	420		95	32	170	170	172	26,6	09m 30s
10.45		671,0	415		165	40	290	300	290	26,8	09m 00s
11.15		671,6	420		152	35	270	272	270	27,1	09m 00s
11.45		672,1	420		155	36	270	275	270	26,9	08m 56s
11.55		672,2	Lunch-break				/				09m 06s
13,45		672,5	420		120	35	170	170	168	24,8	09m 04s
14.15		673,0	420		155	32	268	270	270	23,6	08m 31s
14 45		673,4	420		150	40	270	280	290	22,2	08m 50s
15.15		673,9	420		150	38	260	280	270	19,5	09m 48s
15.45		674,4	420		145	35	265	271	275	20,5	10m 30s
16.15		674,9	420		137	30	270	280	280	19,5	09m 35s
16.45		675,5	420		135	30	275	275	280	21,4	09m 32s
17.15		676.0	420		135	30	280	285	285	21.1	08m 53s
17.45		676.6	420		135	30	270	270	275	21.8	
18.15		677,0	425	2.-	160	30	285	305	310	22,3	8m 15s
18.45		677.5	425	27	160	40	290	300	305	22.4	

DAILY OPERATING REPORT

Gasifier system: Ankur Load: ~~Pump~~/Dryers Date: 18.11.91 .... Operator: WAKATAMA / MAHUFU

Time Of Day	Input Fuel Type	~~Fuel Kg~~ ENGINE HOURS	Output R- Phase V Volt	A Amp	SYSTEM CONDITIONS Gasifier Gastemp In	Gaspress Out	Fabric Filter Gaspress Out	Separator box	Safety filter Gaspress In	Out	Engine Gastemp °C	~~No of bags~~ DIESEL TIME
19.15	COBS	678,0	425	27		30	280	145	290	290	23.5	
19.45		678,5	425	26		35	293	160	300	300	24.3	8m 23s
20.15		679.0	425	26		35	298	165	300	305	24.5	7m 39s
20.45		679.5	425	26		37	2,95	170	305	305	24,3	8m 01s
21.15		680,0	425	26		40	306	182	315	315	24,1	8m 08s
21.45		680,5	430	27		45	310	190	325	325	24,3	
22.15		681.0	430	27		45	310	195	325	325	24.2	8m 10s
22.45		681.5	430	26		40	310	190	320	325	24.1	8m 16s
23.15		682.0	430	27		35	310	180	320	320	24,8	7m 54s
23.45		682,5	425	26		30	280	170	320	320	21,9	
		682,9										

ANNEX O - TEST RESULTS

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

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	

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

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.