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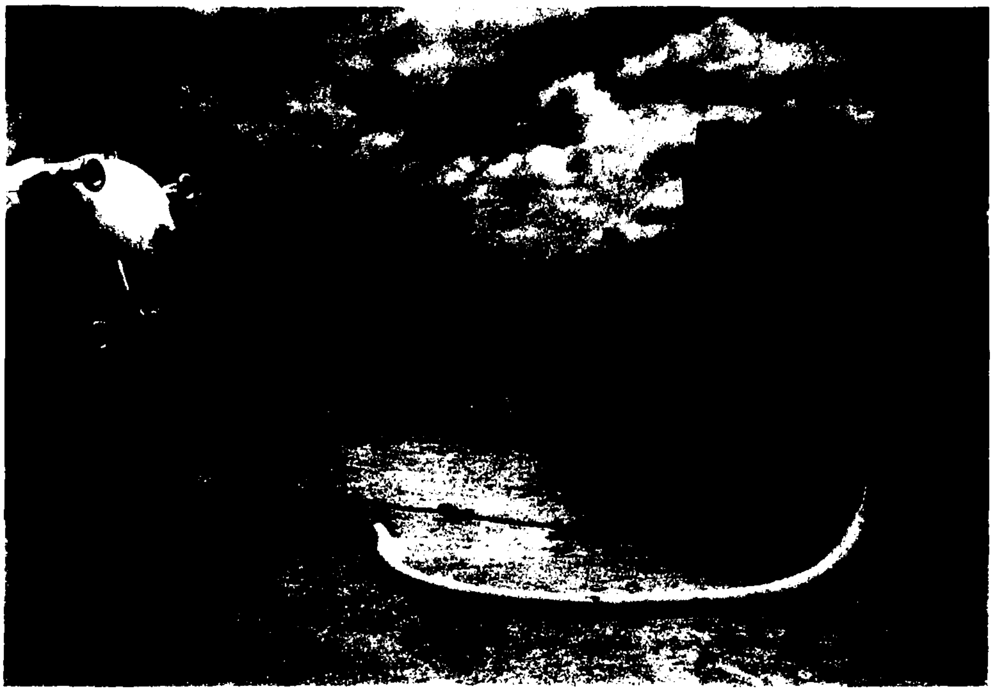
EMPTYING ON-SITE EXCRETA DISPOSAL SYSTEMS

Field Tests with Mechanized Equipment in Gaborone (Botswana)



ANDREW BOESCH and ROLAND SCHERTENLEIB

International Reference Centre for Waste Disposal (IRCWD)
Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland

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EMPTYING ON-SITE EXCRETA DISPOSAL SYSTEMS:

FIELD TESTS WITH MECHANIZED EQUIPMENT IN GABORONE (BOTSWANA)

Andrew Bösch and Roland Schertenleib

International Reference Centre for Waste Disposal (IRCWD)
Ueberlandstrasse 133, 8600 Duebendorf, Switzerland

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SUMMARY

This report describes field tests of three prototype pit latrine emptying systems, a hand operated diaphgram pump and two vacuum tankers in regular service in Africa. Numerous sludge samples were taken and their viscosities and compositions measured to establish limits for the types of sludges that can be removed by each system.

Based on this fieldwork, a matrix for selecting suction equipment (vacuum pumps) for specific applications is proposed. Taking into account the performance of existing components, seven types of tankers have been identified and the appropriate access conditions and sludge types indicated for each tanker type. For areas where access to latrine pits is very difficult, suitable remote emptying systems will be required.

Draft specifications are recommended for the design of suction tankers suitable for use in Third World countries. The main features of the specification are:

- liquid ring vacuum pump for high capacity suction tankers (pneumatic conveying) and sliding vane vacuum pump for low capacity suction tankers (vacuum system) driven by a power take-off (PTO) system;
- fully opening of tank rear door for all tankers and an additional mechanical tank cleaning facility (tank tipping cylinder or pushing plate) for tankers capable of shifting very viscous sludge;
- chassis-mounted clean water tank with a capacity of 500 ℓ or, in the case of big tankers, 10% of the slurry tank capacity;
- lever-operated slide or globe valves of a 100 mm inlet diameter and of a 200 mm outlet diameter;
- sludge hoses of 100 mm diameter and air hoses of 75 mm diameter;
- air bleed nozzles for high capacity tankerr.

An empirical relationship between sludge viscosity and sludge composition has been developed which will be very useful in predicting the flow behaviour of sludges, thereby no longer requiring the use of expensive and sophisticated viscometers.

In addition, recommendations are made for future research and development, and the implications of mechanical pit emptying on the planning of sanitation programmes are discussed.

1. INTRODUCTION

1.1 Background

With the increased activity in the field of excreta disposal promoted by the UN Water and Sanitation Decade, substantial progress will have to be made in the provision of sanitation for at least 1500 million people who at present are served by totally inadequate facilities. Most of these people live in the periurban and rural areas of developing countries with incomes of less than US $ 500 per year. They are not only unable to afford piped sewers, but these may also be technically inappropriate for them. Therefore, there is a need for alternative, well-proven technologies which, if properly designed, will safely dispose of excreta on site, and will also be socially accepted by the communities and affordable to the householder. The most important technologies benefiting millions of people are the Ventilated Improved Pit (VIP) latrine and the Pour-Flush (PF) toilet 1/(*).

These latrines may be relocated onto a new site when their pits are full, or a second pit used while the contents of the first are left to decompose into harmless and inoffensive material. In some cases, however, it may be necessary to empty a pit containing fresh, pathogen-laden excreta. This is likely to occur if the householder cannot afford to rebuild his latrine, or if there is insufficient space on the plot to accommodate a second pit. These constraints are common in urban and periurban low-income areas. In this context, many villages with high population densities must be regarded as urban areas.

The magnitude of the pit emptying problem is therefore considerable and rapidly increasing as many cities and towns in developing countries are embarking on major latrine-building programmes. Many of these sanitation programmes are being implemented without sufficient consideration to pit emptying. In particular, the emptying procedure is rarely considered as imposing any constraints on the sanitation programme chosen.

(*) All references are given at the end of this report, page 76

In 1981, the International Reference Centre for Wastes Disposal (IRCWD) initiated a project to investigate the pit emptying problem. Field studies on existing emptying services and on pit latrine contents were conducted in Dar es Salaam (Tanzania) and Gaborone (Botswana). In addition, emptying devices used successfully for many years in the Far East, were evaluated during an extensive mission to Japan, China, the Republic of Korea and Thailand. The outcome of these activities was reported in three working papers 2/-4/ and 5/.

These studies revealed that in many Third World countries, pit emptying services using vacuum tankers developed in industrialized countries have been in operation for many years. However, most of these services have proved inefficient and unsatisfactory. Four main shortcomings were identified during the study:

1. The physical size of the machinery can prevent adequate access to latrines. Currently available vacuum trucks are of sizes from two tonnes upwards and are too big to be able to drive into the hearts of many ancient cities or urban squatter settlements with their narrow, winding streets only suited to pedestrian traffic. Depending on sludge consistency and strength of the vacuum pumps, pipes of up to 70 m length can be used. However, in many cities and towns, the nearest suitable roadway for a sizeable number of houses is much further away. Even in planned sites and service schemes, where road access is generally good, latrines are often situated at the back of the plot, creating unnecessary difficulties for collection workers.

2. Vacuum systems cannot handle some of the thicker, compacted sludges in old pit latrines. In a few cases this can be overcome by mixing extra water with the sludge, but usually this will not be practical and an alternative method for pit emptying is necessary.

3. Maintenance of vacuum tankers is often poor. Their engines must be kept running all day, either to move the truck or to operate the vacuum pump when stationary. This causes rapid wear and makes them particularly susceptible to breakdowns if preventive maintenance is neglected. Fuel consumption is high, and vacuum trucks may be prime targets for cuts in fuel supplies if the operating agency is forced to limit its expenditure.

4. Management and supervision of the emptying services are often ineffective. For instance in areas where the fleet of available vacuum tankers is far too small compared to the emptying demands, the crews

try to serve as many houses as possible instead of trying to empty each pit properly. This behaviour can easily be explained by the fact that a house owner will only be served by the crews if he or she is willing to pay, in addition to the official fee, a large sum directly to the crew.

Based on these studies, IRCWD suggested that further investigations and tests should be undertaken in the laboratory and in the field to develop new or adapt existing equipment, while taking into account the difficult conditions encountered in many developing countries.

At that time, similar development work was already under way in the U.K., where the British Overseas Development Administration (ODA) contracted the Building Research Establishment (BRE) to develop appropriate methods for desludging on-site sanitation systems. Following suction trials with various pumping systems, BRE produced a specification for a suction tanker, which resulted in the design and construction of the BREVAC prototype. A similar project was initiated in Sweden. The Swedish International Development Authority (SIDA) appointed the National Institute for Building Research (SIBR) to conduct a project for bringing together Swedish expertise in the manufacture of pumping equipment and motor vehicle manufacture. The ROLBA prototype, based on a conventional Swedish vacuum tanker, was built for this project. A third prototype of emptying equipment was developed by ALH in the U.K. and is based on the principle of a vacuum excavator used to remove small quantities of earth in gas mains.

1.2 Scope of the Field Trials

In 1983, all these prototypes were ready for field trials. For several reasons (see section 1.4) it was agreed among the parties involved to conduct the trials in Gaborone, Botswana. The tests were conducted from October 1983 to February 1984 by the Gaborone Town Council (GTC) crews under the technical supervision of IRCWD and the Government of Botswana, and with the financial and technical support of TAG, ODA and SIDA.

The objective of these field tests was to determine the technical limits of the prototypes in handling the material encountered in pit latrines, even though it was recognized that a testing period of only a few months would be too short to assess the suitability of the different equipment with regard to long-term operation and maintenance.

1.3 Conditions in Gaborone

Gaborone, which is the capital of Botswana, is a well-structured, relatively new town, situated on the Ngotwane River and within a few kilometers of South Africa (see map on page 6). The town which extends about five kilometers in all directions, has a population of over 60,000 people. Although it is growing rapidly with new suburbs developing almost every year, the physical structure is well planned and a network of roads with modern roundabouts connects all districts. As a result, almost all house plots and hence latrines are easily accessible by road even with large-sized vacuum tankers. It has to be noted, however, that these optimal access conditions are not typical of Third World countries. In cities such as Dar es Salaam, for example, access to the latrines is often very difficult (see section 6.1, page 35).

The area of Gaborone is divided into different districts. About 65 % are sites and service schemes, where the Self-Help Housing Agency (SHHA) provides free of charge the house plot including a REC II pit latrine substructure to the inhabitants. This is part of a Ministry of Local Government and Lands aid project in which 100 REC II are being built every month. The remaining 35% of the area is subdivided into low, medium and high-cost housing schemes in which all houses are connected to the sewerage network.

The Gaborone Town Council is well organized and able to serve the whole site and service area with only three vacuum tankers. There is no waiting list for the plot holders to have their pit latrines emptied. One of the reasons for this good service is that the vacuum tankers are quite well-maintained because almost all spares can be obtained directly from South Africa, although with some delays. During the test period, even the upkeep of the new, sophisticated and powerful equipment was satisfactory and is described in chapter 9, page 60.

1.4 Why Tests in Gaborone ?

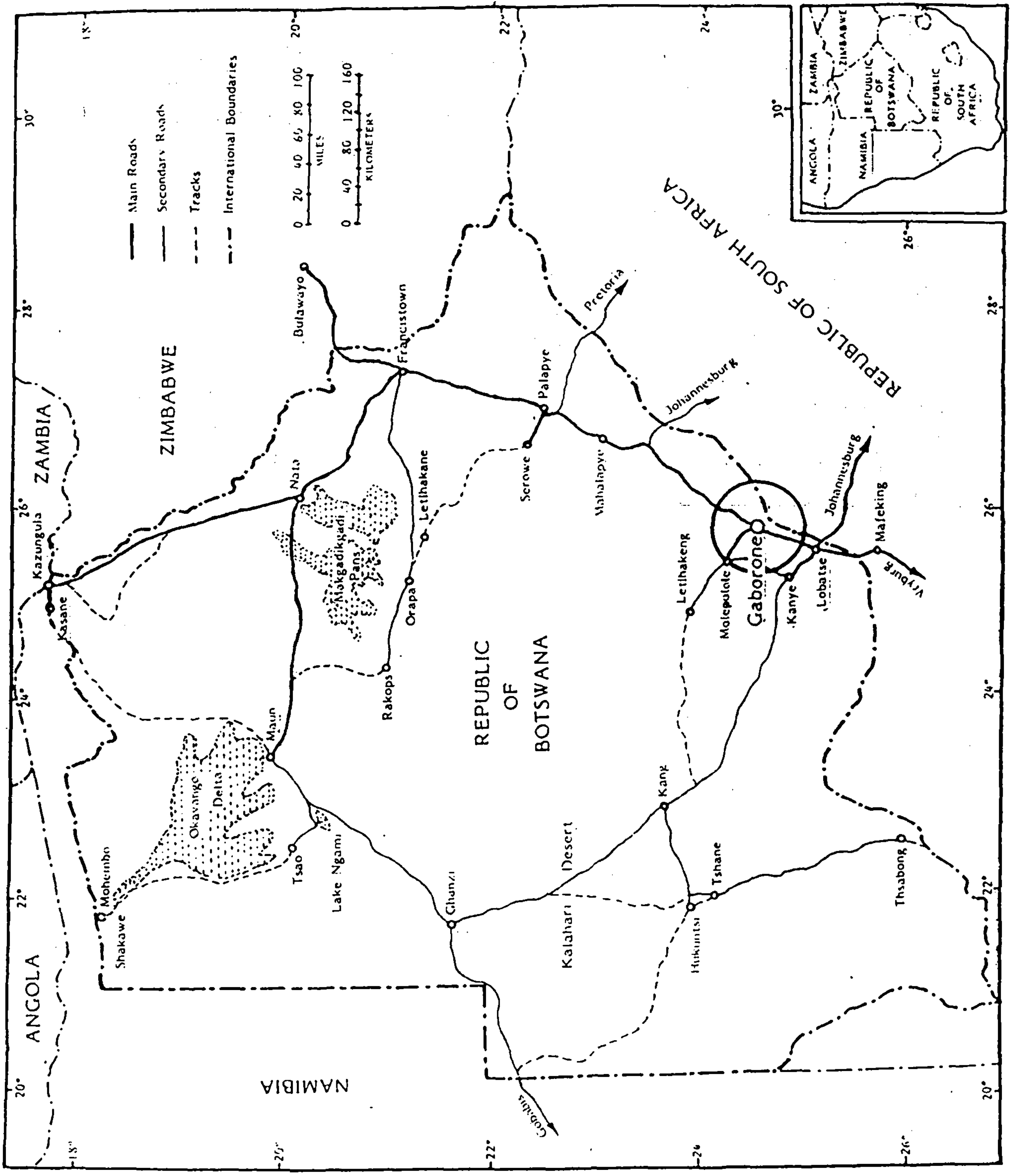
Despite the fact that the conditions are in many respects not typical of Third World countries, there were several good reasons for conducting the tests in Gaborone, Botswana.

- There are many different types of latrines and hence different pit contents available within reasonable distances. This was the most important criterion because the main purpose of this project was to establish limits in pumping different sludge types.

- When IRCWD became involved in the field trials with different prototypes, it had already been decided that the BREVAC and the ROLBA tankers would be tested in Gaborone. In order to be able to compare the performance under similar conditions, all the equipment involved had to be tested at the same location.

- The Gaborone Town Council showed great interest in the field tests and offered considerable logistic support from the very start. This was of utmost importance for conducting and finishing the trials within a reasonable time period (4-5 months).

Map of Botswana



2. SLUDGE REMOVAL TECHNIQUES

As the latrine pits contain different sludge types (from low to high viscosity sludge), different techniques have to be applied to remove them. The literature refers to vacuum system and pneumatic conveying, i.e. air drag, plug drag and 'suck and gulp' system.
To distinguish between these systems, it is necessary to consider not only the performance of the vacuum pump used, but also the design of the hose inlet and the manner in which it is used.

To clarify the terms used in this report they are defined as follows:

2.1 Vacuum System

This system operates with a high vacuum but low airflow rate. For this reason, most of the vacuum tankers are equipped with low-volume sliding vane vacuum pumps which create a vacuum of about 0.8 bar and flow rates between 2 to 10 m^3/min. Some manufacturers prefer liquid ring pumps especially on large tankers. The description and comparison of both options are given in Appendix IV. Transportation of the sludge is by means of the hose inlet being permanently submerged in the material to be shifted and by the atmospheric pressure acting on the surface of the sludge and forcing it along the hose into the holding tank 6/. Because the hose inlet is permanently dipped into the sludge, the material to be transported along the hose has to be liquid enough to flow. Therefore, the main problem with vacuum tankers is their ability to remove liquid and thin sludges only.

To achieve the most powerful suction pull possible, the valve on the tank is closed until a high vacuum is created. When the valve is opened, a high suction power is available for a short time, until the vacuum is reduced. This procedure may have to be repeated several times and may be very slow due to the amount of time needed to evacuate the tank each time. This depends on the size of the tank and the flow rate of the vacuum pump a/.

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a/ The time required to create a vacuum of 0.5 bar in the 7 m^3 POOLE-tank when the air filter was clean, amounted to 5 min, and 15 min when the filter was clogged (see page 40, para. 1).

2.2 Pneumatic Conveying

This system works on the principle of entraining the material to be transported in a high velocity air stream. The optimum velocity, however, depends very much upon the type of product and the pipeline in which the material is being conveyed (see Appendix I).

To introduce air into the pipe, three techniques can be used:

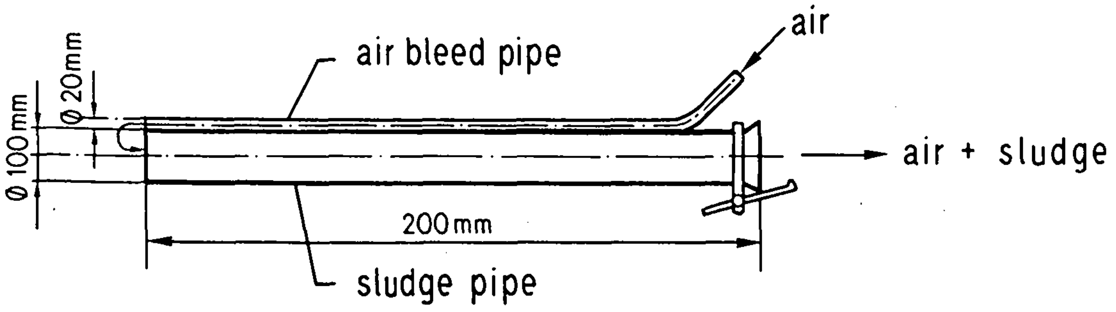
a) constant air drag system

This method requires the hose inlet to be held a few centimeters above the surface of the material to be shifted. Due to the very high velocity of air, particles of sludge are suspended in the air stream and drawn along the hose into the holding tank 7/, 8/. This system, however, does require some operating skill and, as the hose inlet must be held a few centimeters above the surface of the sludge, it is very tiresome. In addition, it calls for large centrifugal fans to supply the necessary airflow (see page 68, para. 4).

b) air bleed nozzle

An air bleed nozzle is composed of a rigid pipe connected to the inlet end of the sludge hose with a small air bleed pipe attached to its side (see Fig. 2.1). This pipe allows air to enter the end of the hose system, and thus maintains the airflow necessary for the transport of the sludge particles. When the nozzle inlet is immersed in the sludge, air is drawn down the air bleed pipe which is open to the atmosphere at its top end. Compared to the constant air drag method, this system has the advantage of not requiring such large centrifugal fans.

Figure 2.1 Air Bleed Nozzle



c) plug drag ('suck and gulp') system

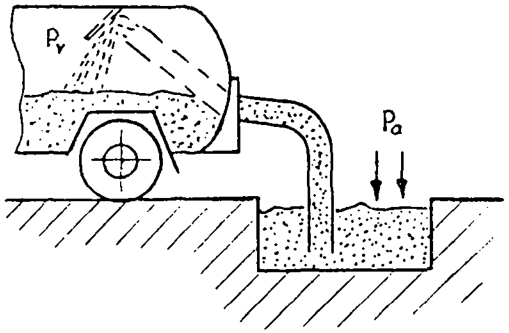
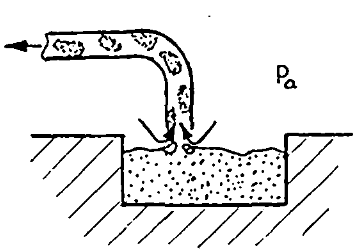
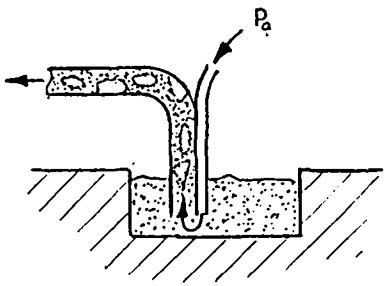
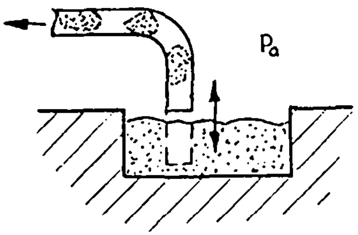
If the airflow rate is too low to allow work with a constant open hose end on the surface of the sludge or if no air bleed nozzle is available, pneumatic conveying can nevertheless be achieved by the so-called 'suck and gulp' or 'plug drag' technique. This method relies on raising and lowering the hose inlet in and out of the sludge, which gives the vacuum pump time to create a new vacuum inside the slurry tank between each up and down movement. By pulling the hose periodically out of the sludge, a high velocity air stream passes through the hose for a short moment, until the vacuum inside the tank is reduced thereby carrying along the heavy particles.

This system, however, only works well if the pump capacity is adequate to create quickly a new vacuum inside the slurry tank between each up and down movement of the hose. This mode of transporting the sludge along the hose is actually a combination of air drag and vacuum system and referred to in this report as the plug drag system.

A summary of the different sludge removal techniques is given in Table 2.1, page 10.

Table 2.1 Summary of the Different Sludge Removal Techniques

SLUDGE REMOVAL

VACUUM SYSTEM	PNEUMATIC CONVEYING		
	constant air drag system	air bleed nozzle	plug drag system
			
high vacuum low airflow	low vacuum high airflow	high vacuum medium airflow	high vacuum medium airflow
atmospheric pressure (p_a) acting on the surface forces the sludge along the hose into the holding vacuum tank (p_v). The hose inlet is permanently submerged in the sludge.	particles of sludge are suspended in the very high air stream and drawn along the hose into the holding tank. The hose inlet is to be held above the surface of the sludge.	atmospheric pressure (p_a) forces air down the air bleed pipe and thus maintains the airflow necessary for the sludge particles.	air drag effect obtained by raising and lowering the hose inlet in and out of the sludge.

3. DESCRIPTION OF THE EQUIPMENT TESTED

During a 4-month period, two vacuum tankers in regular service in Africa, three prototype pit latrine emptying systems and a hand-operated diaphragm pump were tested systematically:

- CALABRESE Tanker	Vacuum system in use by City Council, Dar es Salaam, Tanzania; manufacturer: CALABRESE, Italy
- POOLE Tanker	Vacuum system in use by Town Council, Gaborone, Botswana; manufacturer: POOLE-Rosslyn (Pty) Ltd., South Africa
- ROLBA Tanker	Prototype suction system designed and manufactured by ROLBA to specification by Ragn Sells and SIBR, Sweden, with SIDA backing
- BREVAC Tanker	Prototype suction system designed and manufactured by Airload Engineering to specifications by BRE, U.K., with ODA backing
- ALH Emptying Equipment	Prototype remote suction system designed and manufactured by ALH-Systems, U.K.
- BUMI Hand Pump	Diaphragm hand pump, designed and manufactured by Dunlop, Zimbabwe

The ROLBA and the BREVAC tankers and the ALH equipment have all been specifically designed as possible solutions for emptying on-site excreta disposal systems and have never before been tested under Third World conditions.

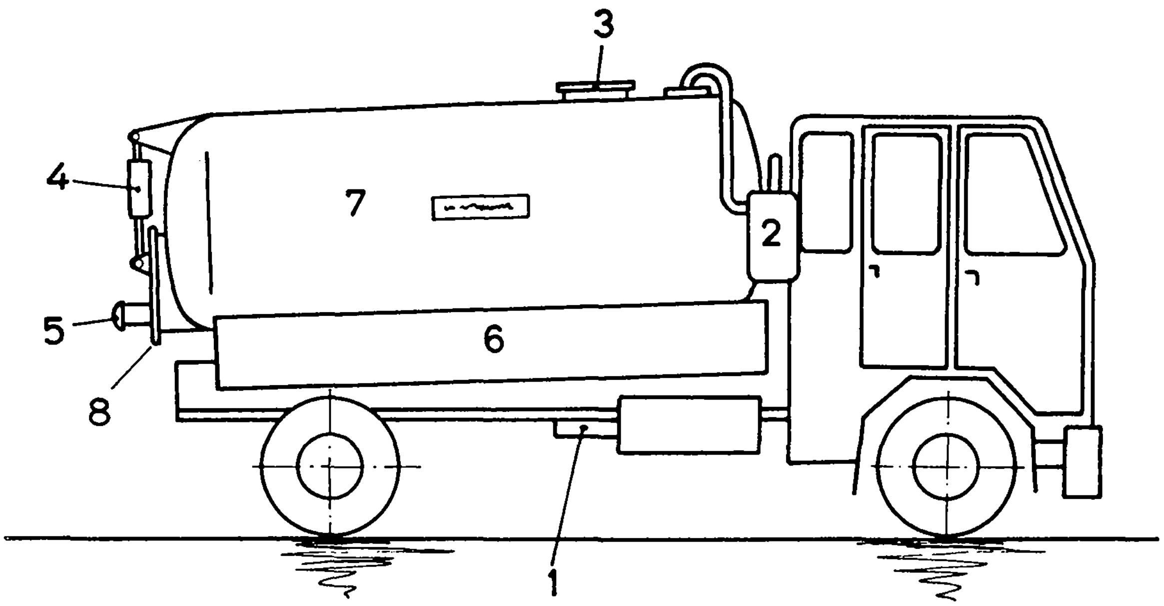
3.1 CALABRESE Tanker

The CALABRESE is a conventional medium-sized vacuum tanker without special accessories, equipped with a low volume sliding vane vacuum pump. The tank has a 4.5 m^3 capacity and, in order to facilitate discharging, it is mounted at a slight angle on the chassis. At the rear, the tank is equipped with a hydraulically-operated door onto which both the 100 mm suction and discharge valves are mounted, and two sight glasses fitted at different heights to indicate when the tank is full. The small rear door is used for cleaning any accumulated material (sand, gravel, rags, etc.) at the bottom of the tank. However, on account of the low pump performance, only very thin sludges and liquid can be pumped and therefore the door has not been opened for years. Access into the tank is provided through a top-mounted manhole hatch. The full tank is discharged under pressure by reversing the pump rotor speed.

The suction supply line leaves the tank alongside the hatch and passes a small slurry separator before reaching the vacuum pump. The pump creates a vacuum head of 0.5 bar and a maximum airflow rate of 5.2 m^3/min. It is powered by the V-belt drive connected to the truck's gearbox power take-off, PTO system). Emptying work is carried out with a maximum of 12 lengths of 100 mm heavy duty PVC hoses, each 3 m long with quick couplings.

The whole unit is mounted on a Fiat 110 chassis powered by a 90 kW diesel engine. The performance of the vacuum pump enables the tanker to be used as a vacuum system.

Figure 3.1 CALABRESE Tanker



1. sliding vane vacuum pump
2. slurry separator
3. hatch
4. hydraulic door opening cyl.
5. suction and discharge valves
6. hose container
7. slurry tank
8. rear door

Performance

Truck	chassis:	Fiat 110 with 90 kW diesel engine
	superstructure:	4.5 m^3 tank (Calabrese, Italy)
	overall width:	2.4 m
	overall length:	5.7 m
Pump	type:	sliding vane
	max. airflow rate:	5.2 m^3/min.
	max. vacuum head:	0.5 bar
Hose	length:	maximum 36 m (12 x 3 m)
	diameter:	100 mm

For specification comparison see Table 3.1, page 27

3.2 POOLE Tanker

The POOLE is a conventional large-sized vacuum tanker equipped with a low volume sliding vane vacuum pump. The 3.4 m long oval tank has a capacity of 7 m^3 and is permanently fixed to the chassis. Fitted on its rear end are a sight glass level gauge to indicate when the tank is full and a 100 mm suction flange with a lever-operated slide valve. Discharging of the full tank is carried out under static head through a 250 mm gravity outlet flap valve. In order to clean the interior of the tank, access is provided through a top-mounted manhole hatch, 600 mm in diameter. A safety valve is fitted to its cover to reduce the vacuum when the tank has reached its full capacity.

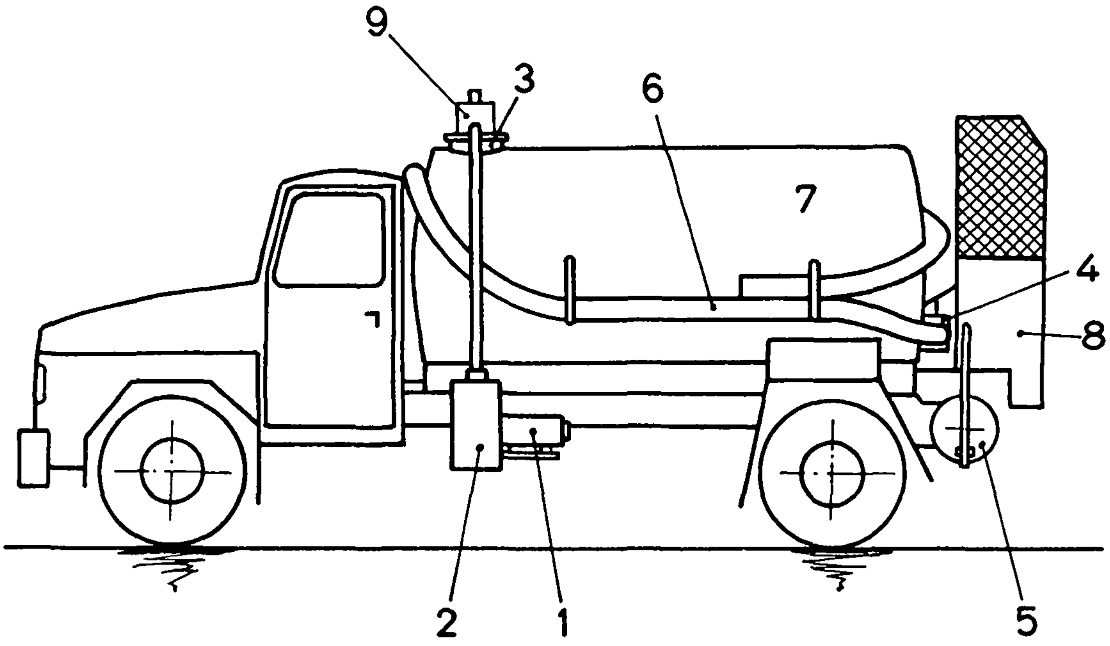
The suction supply line leaves the tank through the hatch cover to a small water separator approximately 320 mm in diameter, and from there through a paper filter unit to the vacuum pump. The pump is an air convection cooled sliding vane type (see Appendix V, page 1,2) which creates a vacuum head of 0.67 bar and a maximum airflow rate of 2.3 m^3/min. It is mounted on a back stage and driven by an auxiliary one-cylinder Lister diesel engine which is started by a hand crank (see photo No. 4, page 39).

The Gaborone Town Council possesses three vacuum tankers, two of which are made up as described above. As regards the third tanker, the vacuum pump is driven by a power take-off (PTO) system from the truck's gearbox. Since the additional Lister diesel engine is not used, the free space at the back of the tanker is utilized as a platform with railings and seats which provides enough room for three additional crew members. For pit emptying, the tanker is equipped with the following tools:

- one 15 m long, 100 mm flexible one-piece heavy duty PVC hose carried wrapped around the tank
- a watering can to transport clean water to wash the hose after work is completed
- four pairs of gloves
- one brush
- one crowbar

The whole unit is mounted on a Toyota DA 116 chassis powered by a Toyota 105 kW diesel engine. Since 1982, however, all the chassis have been equipped with ADE engines (Atlantis Diesel Engines) which appear to be the most common engine in South Africa as they are manufactured under licence by Daimler Benz, South Africa. As a result, spare parts are obtainable from South Africa without too much delay. The performance of the vacuum pump enables the tanker to be used as a vacuum system.

Figure 3.2 POOLE Tanker



1. sliding vane vacuum pump
2. slurry separator
3. hatch
4. suction valve
5. outlet valve
6. 100 mm hose wrapped around tank
7. slurry tank
8. platform with seats
9. safety valve

Performance

Truck	chassis:	Toyota DA 116 with 105 kW diesel engine
	superstructure:	7 m^3 tank (POOLE, South Africa)
	overall width:	2.4 m
	overall length:	7.3 m
Pump	type:	sliding vane (see Appendix V, page 1,2)
	max. airflow rate:	2.3 m^3/min.
	max. vacuum head:	0.67 bar
Hose	length:	15 m in one piece wrapped around tank
	diameter:	100 mm

For specification comparison see Table 3.1, page 27

3.3 ROLBA Tanker

The ROLBA prototype is a large-sized suction tanker equipped with a heavy duty sliding vane vacuum pump. The 5 m-long tank is subdivided into three chambers, i.e.:

- a 6 m^3 slurry tank fitted with a small rear door (0.4 by 0.45 m) onto which a 75 mm suction valve and a 100 mm suction/discharge valve (lever-operated globe valve) are mounted. A floating ball gauge indicates the level inside the tank, and a level control valve stops the airflow when the tank has reached its full capacity. Two hatches are mounted on the top of the tank. One 410 mm in diameter permits access to the tank for maintenance, the other 290 mm in diameter acts as a pressure safety valve which is essential when operating under pressure to discharge the full tank.

- a large slurry separator equipped with a sight glass, a top-mounted hatch which operates as a pressure safety valve and a level control valve which controls the airflow to the vacuum pump (see Figure 3.4, page 19). All the sludge particles and the liquid carried along with the air settle to the bottom of the separator, which can be drained every evening by opening the draining valve.

- a 1000 ℓ clean water tank with two sight glasses and a top-mounted manhole hatch to fill the tank. To make thick sludge fluid enough to be removed, the high pressure washwater is forced into the pits by a 27 m long, 20 mm Ø flexible hose stored on a reel. The high pressure is provided by a water-stage pump which creates a pressure head of 15 bar at a flow rate of 50 ℓ/min.

The MORO M9 sliding vane vacuum pump (see Appendix V, page 3,4) creates a vacuum head of 0.8 bar and a maximum airflow rate of 17 m^3/min. It is driven by a hydraulic PTO system. The air released through the pump outlet carries along lubrication oil (there is a 4 litre oil tank inside the pump) which is separated from the air by means of an oil separator. It is also drained every evening. The pump is engaged through a PTO control inside the truck cab. As an addition, the vacuum pump can also create a pressure head of approximately 1 bar by means of the load/discharge control valve in order to discharge the full tank under pressure.

The hydraulic PTO (power take-off) system consist of a central oil pump powered by a drive shaft from the truck's gearbox. This oil pump creates the oil pressure in the closed hydraulic system, onto which the hydraulic motor for the vacuum pump and the hydraulic motor for the clean water pump are connected. A 130 ℓ hydraulic oil tank supplies the necessary oil to the system.

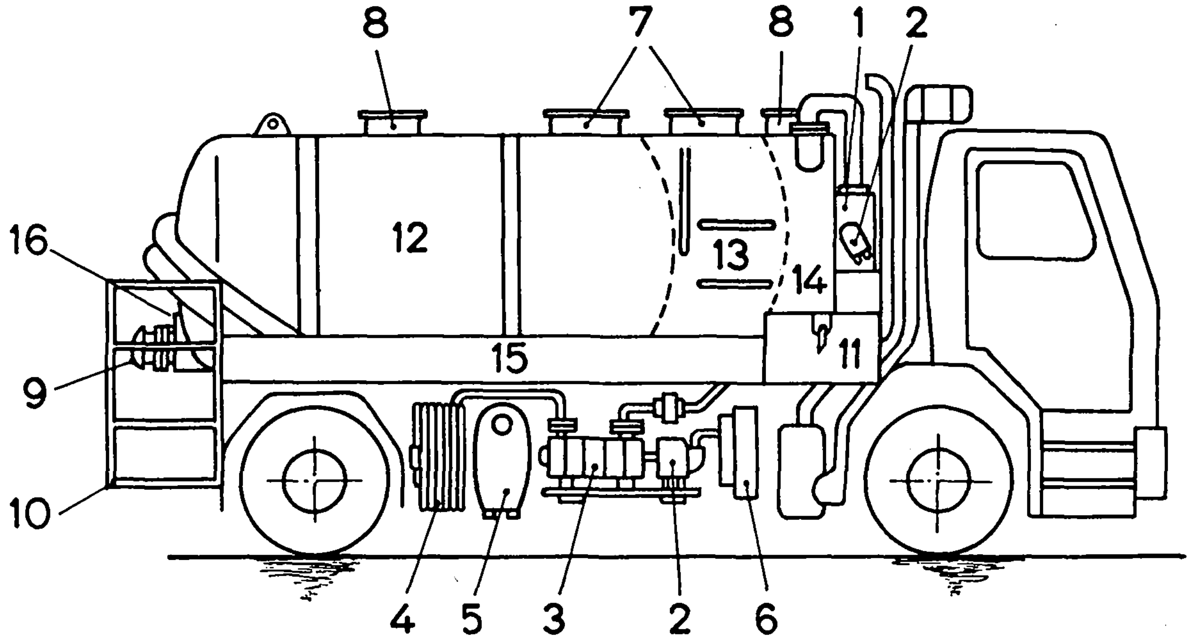
Overheating of the vacuum pump and the hydraulic system are prevented by two separate cooling systems. For the vacuum pump, a closed cooling fluid circuit with a 130 ℓ cooling fluid tank and a cooling radiator is supplied, while the hydraulic oil is cooled directly by passing a cooling radiator incorporated into the hydraulic system. The two electric van-powered radiators are switched on and off automatically when the vacuum pump is operated.

For pit emptying work, the following tools are supplied and carried inside containers attached to the tanker:

- 4 4 m long 100 mm flexible hoses with quick couplings
- 4 10 m long 75 mm flexible hoses with quick couplings
- 1 2 m long 100 mm aluminium nozzle with quick coupling
- 1 3 m long 100 mm aluminium nozzle with quick coupling
- 1 2 m long 75 mm aluminium nozzle with quick coupling
- 1 3 m long 75 mm aluminium nozzle with quick coupling
- 1 75 mm to 100 mm quick coupling adaptor
- 1 crowbar

To carry the whole unit, Ragn Sells and SBRI have chosen a Scania P82H chassis powered by a 155 kW diesel engine. The performance of the vacuum pump enables the tanker to be used both as a vacuum and a plug drag system.

Figure 3.3 ROLBA Tanker



1. sliding vane vacuum pump
2. hydraulic motor
3. washwater pump
4. washwater hose
5. hydraulic oil tank
6. cooling radiator for hydr.oil
7. hatch
8. pressure safety valve
9. suction/discharge valve
10. platform
11. tool locker
12. slurry tank
13. clean water tank
14. slurry separator
15. hose container
16. rear door

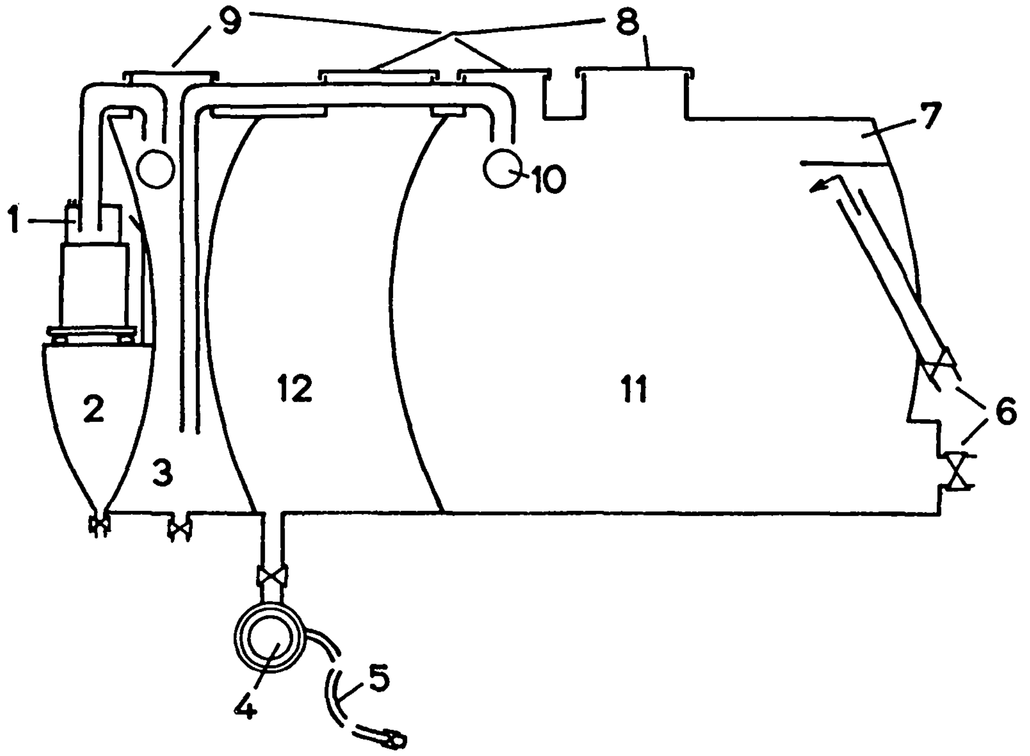
Performance

Truck	chassis:	Scania P 82 H with 155 kW diesel engine
	superstructure:	6 m^3 tank (ROLBA Hedesuna, Sweden)
	overall width:	2.5 m
	overall length:	7.3 m
Pump	type:	sliding vane (see Appendix V, page 3,4)
	max. airflow rate:	17 m^3/min.
	max. vacuum head:	0.8 bar
Hose	length/diameter:	16 m flexible hose/100 mm
		40 m flexible hose/75 mm

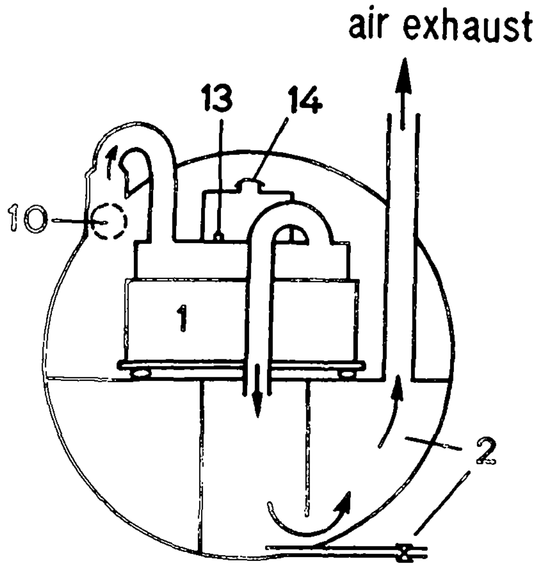
For specification comparison see Table 3.1 page 27

Figure 3.4 Flow Diagrams ROLBA

SIDE VIEW



FRONT VIEW



1	vacuum pump
2	oil separator with draining valve
3	slurry separator with draining valve
4	clean water pump
5	clean water hose
6	suction valve
7	wearing plate
8	manhole hatch
9	pressure safety valve
10	level control valve
11	slurry tank
12	clean water tank
13	lubrication filling plug
14	cooling fluid filling plug

3.4 BREVAC Tanker

The BREVAC prototype is a medium-sized suction tanker with a high performance liquid ring vacuum pump. Its suction unit has special facilities with regard to emptying pit latrines with contents of compact sludge. The whole tank has an overall length of 4.2 m and includes a 4.5 m^3 slurry and a 1 m^3 service liquid (water) compartment.

The slurry tank is equipped with a top-mounted manhole hatch, 460 mm in diameter, and a level control valve which stops the airflow when the tank is full. A floating ball gauge indicates the level inside the tank and a pressure safety valve protects the tank from overpressure when operating in pressure position (discharging of tank). To facilitate tank emptying and cleaning, a hydraulic tipping cylinder inclines the tank to a steep angle (approximately 60°) and its rear door can be fully opened by four handwheels. Attached to the rear door are a 100 mm suction valve (lever-operated slide valve), a 100 mm discharge valve (handwheel-operated slide valve), both angled downwards approximately 30° to the horizontal, and a 75 mm water drain valve. An additional 200 ℓ container for the washwater and a water-stage pump, which creates a pressure head of 7 bar at a flow rate of 40 ℓ/min, are fitted onto the side of the chassis. To clean the latrine and the suction hoses after pit emptying, the clean water pump forces the water through a 16 m by 20 mm hose stored on a reel.

The heart of the suction system is the high performance liquid ring vacuum pump (see Appendix V, page 5) with a suction capacity of 0.8 bar and a maximum airflow rate of 26 m^3/min. To discharge the tank under pressure, the pump can also create a pressure head of approximately 1 bar by means of a load/discharge control valve which reverses the airflow to the slurry tank. A liquid ring pump is capable of handling entrained material and therefore does not need to be protected by a slurry separator. Its function principle, however, includes the use of a service liquid (water in this case), which is supplied through a closed circuit by a water pump coupled to the vacuum pump shaft. After passing the vacuum pump, the water is released through the discharge port along with the pumped air, and then separated from the air inside the water tank by the sudden decrease of the air velocity (see Figure 3.6, page 23). During the discharging operation (tank emptying), the service liquid is returned to the water tank by means of an additional water separator (Figure 3.6, page 23).

The high pressure hydraulic oil necessary to run the hydraulic motor of the vacuum pump, the hydraulic motor of the clean water pump and the tank tipping cylinder is supplied from the central oil pump powered by a drive shaft from the truck's gearbox. The oil for this closed hydraulic system is stored in a 55 ℓ oil tank. The vacuum pump, clean water pump and tank lift are engaged through PTO controls inside the cab.

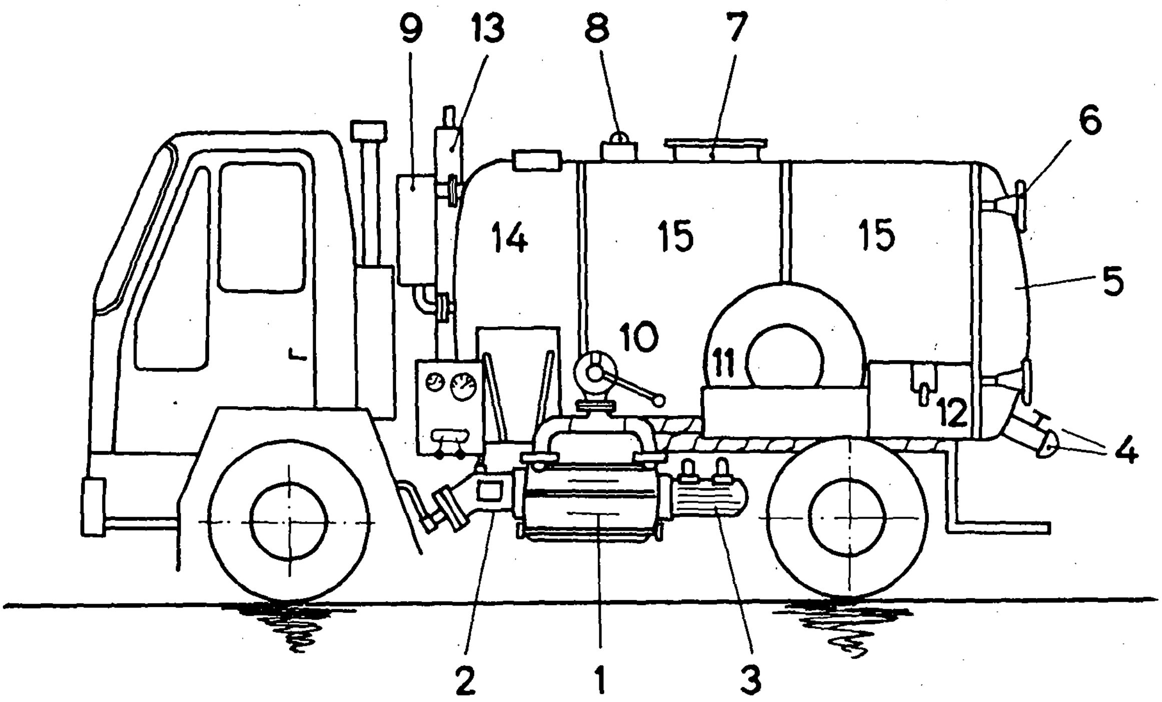
The service liquid (water) and the hydraulic oil are cooled by two separate cooling radiators powered by the truck motor's van.

The following tools carried in a side container are provided for the latrine emptying service:

- 6 3 m long 100 mm heavy duty steel-reinforced rubber hose with quick couplings
- 8 3 m long 100 mm lightweight steel pipe with quick couplings
- 1 8 m long 75 mm heavy duty steel-reinforced rubber hose with quick couplings
- 1 2 m long 100 mm air bleed nozzle with quick coupling
- 1 1 m long 100 mm air bleed nozzle with quick coupling
- 1 2 m long 75 mm air bleed nozzle with quick coupling
- 1 1 m long 75 mm air bleed nozzle with quick coupling
- 1 spare wheel

In response to the request by the Gaborone Town Council, BRE specified a Ford Cargo 1211 chassis with a 85 kW diesel engine for BREVAC. The high performance liquid ring vacuum pump enables the tanker to be used both as a vacuum and a plug drag system. BREVAC also incorporates the air bleed device by the use of air bleed nozzles as a compromise to reduce the need for plug drag operation which can be very tiresome.

Figure 3.5 BREVAC Tanker



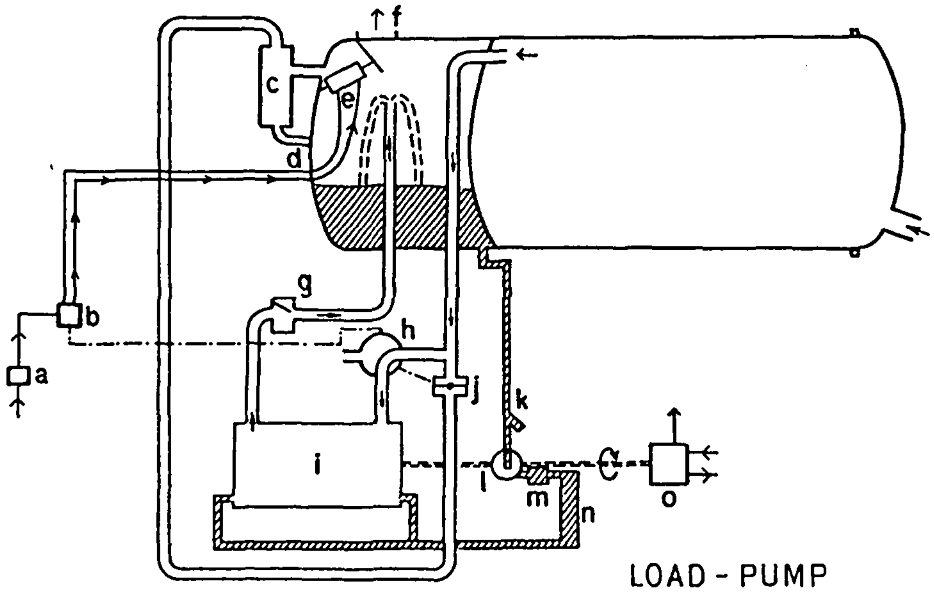
1. liquid ring vacuum pump
2. hydraulic motor
3. service liquid pump
4. suction and discharge valves
5. swing-out rear door
6. handwheel
7. hatch
8. pressure safety valve
9. water separator for discharge air
10. load/discharge control valve
11. spare wheel
12. tool locker
13. hydraulic tank tipping cylinder
14. service liquid (water tank)
15. slurry tank

Performance

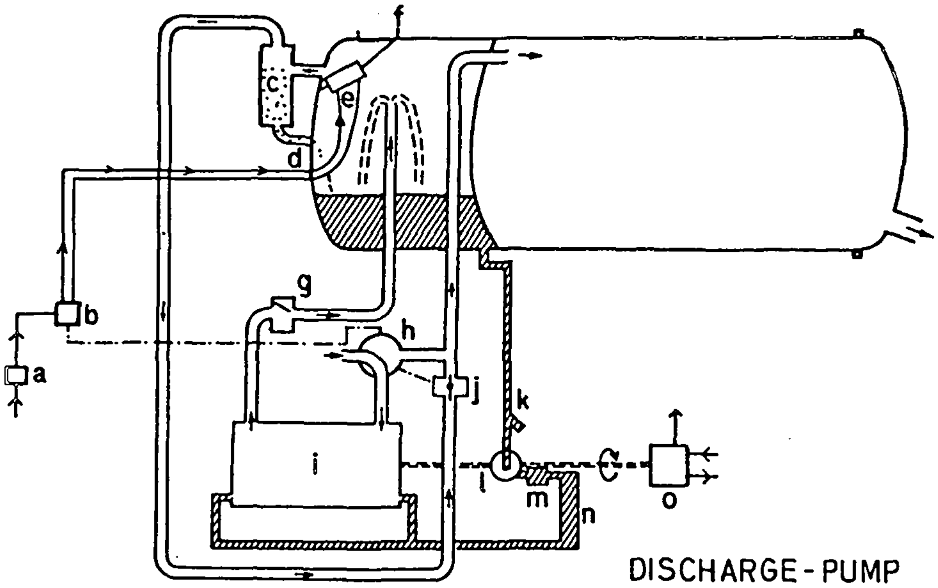
Truck	chassis:	Ford Cargo 1211 with 85 kW diesel eng.
	superstructure:	4.5 m^3 tank (Airload Engineering Ltd. England)
	overall width:	2.4 m
	overall length:	6.7 m
Pump	type:	liquid ring (see Appendix V, page 5)
	max. airflow rate:	26 m^3/min.
	max. vacuum head:	0.8 bar
Hose	length/diameter:	18 m flexible hose/100 mm 24 m steel pipe/100 mm 8 m flexible hose/75 mm

For specification comparison see Table 3.1 page 27.

Figure 3.6 Flow Diagrams BREVAC



LOAD - PUMP



DISCHARGE-PUMP

KEY

a) Pressure Protection Valve (Air supply from air brake circuit)
b) Control Valve (Exhaust cylinder control)
c) Water Separator (Discharge air)
d) Water Separator (Non-return valve)
e) Exhaust Cylinder
f) Exhaust Duct to Atmosphere
g) Vacuum Pump Discharge Non-Return Valve
h) Load/Discharge Control Valve
i) Vacuum Pump
j) Discharge Air Control Valve
k) Vacuum Pump Water Filter
l) Vacuum Pump Water Circulation Pump
m) Vacuum Pump Water Automatic Shut Down Valve
n) Vacuum Pump Water Cooling Radiator
o) Vacuum Pump Hydraulic Motor

3.5 ALH Emptying Equipment

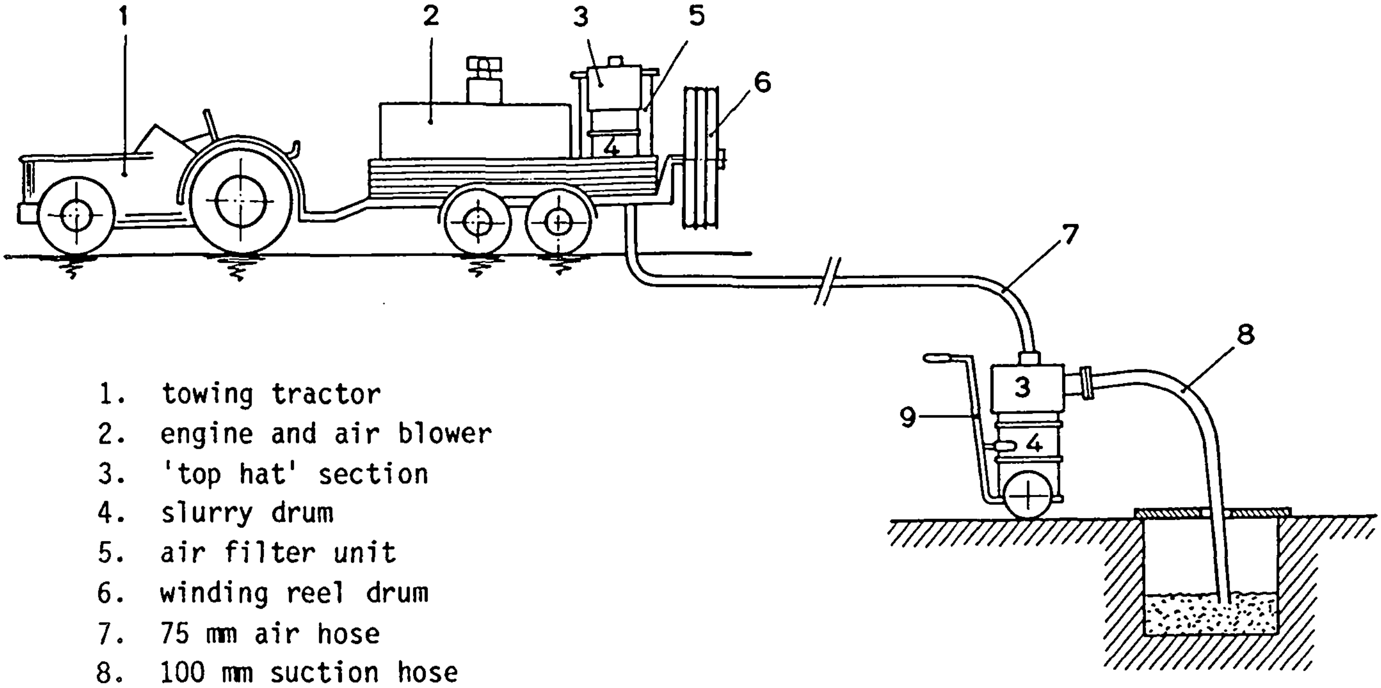
The prototype ALH remote system was designed particularly for use in areas such as squatter settlements where access with conventional suction tankers is not possible. The principle of this system is to move air rather than sludge over long distances, thereby increasing the operating range possibly up to 150 m.

The equipment is trailer-mounted in order to reduce costs and utilize existing vehicles to tow the unit (see photo No. 9, page 47). It consists of a Lister diesel engine, powering a positive displacement air blower and a hose reel capable of carrying a 60 m by 75 mm air hose. Also transported on the trailer are one slurry drum, 'top hat' section, a 5 m by 100 mm sludge hose and the hand drum trolley.

When work is carried out, one end of the 75 mm air hose is fitted to the pump unit on the trailer, while the other end is coupled to the 'top hat' section which fits over a standard oil drum (approximately 0.2 m^3) placed next to the pit (see Fig. 3.7). The vacuum is created in the slurry drum and the content of the pits removed into it by using a short 100 mm plastic hose. The drums are transported to and from the pits by a small hand trolley. For cleaning purpose a washwater-drum with a top-mounted diaphgram hand pump is provided.

The positive displacement air blower (Rootes type, see Appendix V, page 6-8) creates a vacuum head of 0.5 bar and an airflow rate of maximum 23.7 m^3/min. Its intake is protected by an air filter unit which consists of several fabric bags and is equipped with a vacuum relief valve essential to prevent the pump from creating more than 0.5 bar vacuum in the event of a blockage. The performance of the pump enables the equipment to be used as a plug drag system.

Figure 3.7 ALH Emptying Equipment



1. towing tractor
2. engine and air blower
3. 'top hat' section
4. slurry drum
5. air filter unit
6. winding reel drum
7. 75 mm air hose
8. 100 mm suction hose
9. hand trolley

Performance

Engine	air-cooled ST3 Lister diesel engine 20 kW	
Pump	type:	positive displacement air blower (see Appendix V, page 6-8)
	max. airflow rate:	23.7 m^3/min.
	max. suction head:	0.5 bar
Suction hose	length:	5 m
	diameter:	100 mm
Air hose	length:	60 m
	diameter:	75 mm

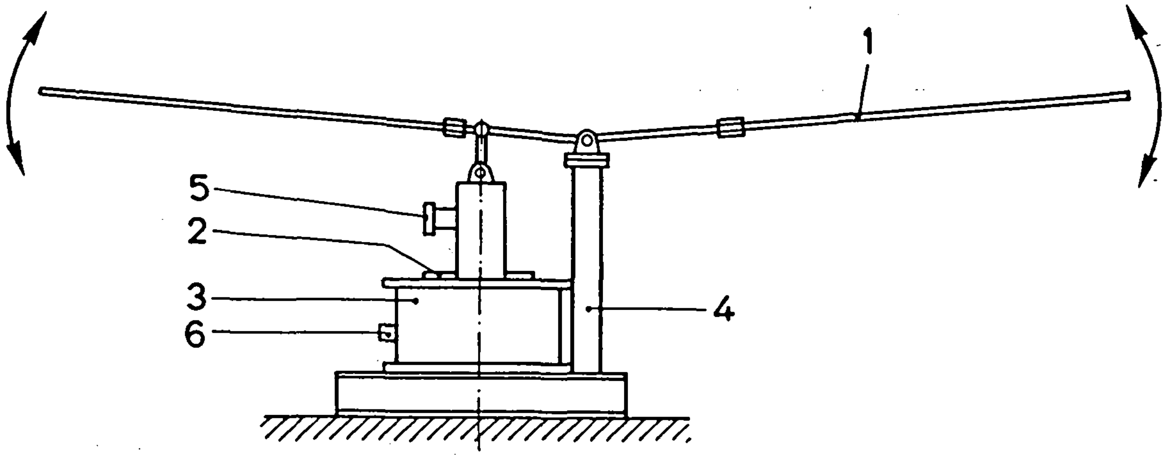
For specification comparison see Table 3.1, page 27

3.6 BUMI Hand Pump

This robust, hand-operated diaphragm pump, with only three wearing parts, has been designed and manufactured by Dunlop, Zimbabwe, to meet the irrigation needs of Zimbabwe's subsistence cultivators and the varied requirements of the commercial farmer.

Although developed for irrigation, the pump has a variety of uses, and has been utilized experimentally for desludging latrines in Zimbabwe. The pump is operated by means of two 2 m long extension bars (handles) allowing for two-man operation. The pump was bolted onto the back of a van to be driven to the latrines.

Figure 3.8 BUMI Hand Pump



1. extension bars (2 m each)
2. diaphragm
3. pump body
4. frame
5. outlet
6. inlet

Performance

Capacity: 4ℓ/stroke (see Appendix V, page 9,10)
Suction head: 0.6 bar
Suction hose: 50 mm ø

For specification comparison see Table 3.1, page 27)

3.7 Specification Comparison of Suction Units

The tables contain all the measurements and performance data of the tested equipment. It should be stressed that the CALABRESE, POOLE, ROLBA and BREVAC are compact self-powered suction tankers, whilst ALH is a trailer-mounted unit and the BUMI a hand-operated diaphragm pump. The costs shown in the last column are based on information given by the manufacturer. It has to be noted, however, that the prices for ROLBA, BREVAC and ALH are prototype prices, whereas the prices of the other units are actual market prices.

TABLE 3.1 Specification Comparison of Suction Units; Part 1

	vacuum pump							suction hose			comments
	Type of air mover	max. air flow m^3/min	rotor speed rpm	max. vacuum head bar	pressure head bar	power required kW	cooling system	diam. mm	length m	air velocity m/sec.	
CALABRESE	sliding vane Becker DKW V3K	5.2	1420	0.5	-	13	air convection	100	36	11	Compact suction tanker
POOLE	sliding vane Comp. Air R 108	2.3	1450	0.67	-	6	air convection	100	15	4.9	Compact suction tanker
ROLBA	sliding vane Moro M9 A	17	800	0.8	1	25	cooling oil with cooling radiator	100 75	16 40	36 64	Compact suction tanker
BREVAC	liquid ring Airload PV 71	26	960	0.8	1	40	closed water circuit	100 75	42 8	55 98	Compact suction tanker
ALH	pos.disp. air blower Peabody Holmes 68 RBT	23.7	2200	0.5	-	20	air convection	100 75	5 60 (air hose)	45	Trailer-mounted suction unit with drums, towed by tractor
BUMI-PUMP	diaphragm hand pump Dunlop Zimbabwe	4 ℓ/ stroke	-	0.6	-	2 men	-	50	5	-	hand operated diaphragm pump

TABLE 3.1 Specification Comparison of Suction Units; Part 2

	slurry tank			Clean water facility			Data of truck						Cost
	diam. mm	length m	capacity of tank m^3	capacity of water container	pressure of water pump bar	water flow of pump l/min	power kW/diesel petrol	wheel base m	track front m	width m	length m	weight kg	US $
CALABRESE	1500	3.7	4.5	-	-	-	90 diesel	2.9	1.85	2.4	5.7	11 000	31'000
POOLE	Oval 1.8 x 1.4 m	3.4	7	-	-	-	105 diesel	4.5	1.675	2.4	7.3	12 000	29'500
ROLBA	1500	5.0	6	1	15	50	155 diesel	4.2	2.3	2.5	7.3	17 500	40'000
BREVAC	1550	4.2	4.5	0.2	7	40	85 diesel	3.6	2.1	2.4	6.7	12 500	49'000
ALH	drums 600	0.8	0.2	0.2	diaphragm hand pump		20 diesel	trailer	-	-	-	3 000	28'000
BUMI-PUMP	-	-	-	-	-	-	-	-	-	-	-	-	240

4. TEST PROCEDURES

To achieve comparable results, the same test procedure was used for the testing of each piece of equipment:

Pits were emptied, at a normal working pace until further removal became impossible. For the CALABRESE, POOLE and ROLBA tanker this limit-point was easy to establish since the sludge started to flow back from the suction hose into the pit. This flow-back behaviour did not occur with BREVAC and the ALH equipment, but work was stopped as soon as the sludge removal rate fell to a low level.

After finishing with the suction work, a 1-ℓ sample was taken from the sludge remaining in the pit for analysis of moisture and volatile solids content and a viscometer test (see Appendix III). This represented the composition and flow behaviour of the heaviest sludge removable by a machine for a defined pit depth and hose length. Table 11.2 on page 71 shows the performance limits of the equipment tested for a 1.5 m and a 3 m deep pit and the maximum possible length of suction hose. It also gives the average number of latrines served per day.

The relation between sludge composition (water and volatile fraction) and flow behaviour can be seen in Figure 5.3 on page 33, which demonstrates quite a good correlation between the three parameters.

To provide an indication of how easy each machine is to use and its efficiency, a record was kept of each latrine emptied and the time taken for setting-up, dismantling and cleaning the equipment, and the time taken to empty the pit (see Appendix VIII, Measure Protocol). Emptying time, however, depends to a considerable degree on the flow behaviour of the sludge as well as on the condition and contents of the pits. Almost all the latrine pits contained rubbish which caused frequent blockages in the suction hose. During the tests, blockages were caused by bottles, shoes, rags, paper, batteries, stones, wire and pieces of wood, occasionally more than six times per pit.

This problem of blocked hoses will vary from place to place. For instance in Dar es Salaam, far less rubbish was encountered in the pits, probably because the people tend to reuse these materials rather than throw them away.

5. CHARACTERISATION OF THE MATERIAL TO BE SHIFTED

The theoretical basis for the rheological analysis of sludges is discussed in Appendix II. The laboratory analysis of the sludge samples is described in Appendix III.

As outlined in Appendix II (Theoretical Foundation), different methods of finding a characteristic parameter representing flow behaviour of sludges were investigated. It was finally decided that the appropriate method was to compare flow curves plotted by a viscometer. As excreta-derived sludges exhibit thixotropical flow behaviour, two different flow curves were plotted, i.e.: TE curve (Thixotropic Equilibrium) and DTS curve (completely Destroyed Thixotropic Structure) see Figure 5.1, page 32. To classify the viscosity of each sample its DTS curve was compared with the viscosity ranges shown in Figure 5.2, page 32. These ranges were based on those established by BHRA (British Hydromechanics Research Association 9/) and subdivided further into the ranges low$^-$, low, low$^+$, medium, medium$^+$, high$^-$, high and high$^+$.

In addition to the viscometer test, each sludge sample was analysed for its water content and volatile and non-volatile fraction (see Table 5.1, page 31).

The analyses have indicated the existence of a correlation between the sludge composition (water and volatile fraction) and flow behaviour. On account of this finding, an empirical relationship between these three parameters could be developed. Figure 5.3 on page 33 shows a proposed classification of viscosity based on sludge composition. Apart from a few samples which do not fall into the correct viscosity class, the measured samples show a good correlation between the sludge composition and the four classes established. Based on experience gathered during field analyses, it can be concluded that this Figure 5.3 will be a useful aid in predicting the flow behaviour on the basis of the sludge composition, thereby no longer requiring the use of expensive and sophisticated viscometers. The four viscosity classes cover the following ranges:

① low$^-$
② low - low$^+$
③ med. - med.$^+$
④ high$^-$- high$^+$

Thicker sludge with a high organic (volatile) content shows a more pronounced loss of viscosity as the flow rate is increased, and a more pronounced thixotropic flow behaviour. This is shown by the DTS curve which is at a much lower position than the TE curve (see Figure 5.1).

The slope of a flow curve is related to viscosity, i.e. a steeper slope indicates a more viscous material. The practical implication of shear thinning (a decrease in viscosity with increasing shear rate, see Figure 5.4, page 33) is the fact that getting the sludge to move is more difficult than overcoming flow resistance at high flow rates. From Figure 5.3, page 34, it can be seen that with a constant water fraction and increasing organic (volatile) content, viscosity increases. On the other hand, a sludge with only 30 % water may show the same flow behaviour as a sludge with a water content of 80 %, due to the difference in the organic fraction.

For example:

Sludge No.	Water content %	Volatile content % (organic)	Density kg/m³	Character
49b	31.9	3.1	1'628	medium
6	85.0	10.0	1'051	medium

Compare with Table 5.1 on page 31.

One explanation for this behaviour could be that, in the case of a sludge with high organic content, most of the water is bound into the microstructure of the sludge, while for a very sandy sludge there is free water which probably lubricates the viscometer probe.

Another factor which must be taken into consideration when comparing the 'pumpability' of sludges is the density. For instance both sludges listed above show a medium flow behaviour. It is obvious, however, that sludge No. 49b requires more suction power to move because it contains a lot of sand and its density is 1'628 kg/m^3. In contrast, sample No. 6 has a density of only 1'051 kg/m^3. The range of density measured varies from 1'027 to 2'159 kg/m^3.

The samples found in Gaborone fell into the range of composition:

Water:	13.0 % - 89.0 %	Average:	52.6 %
Volatile:	2.0 % - 11.2 %	Average:	5.9 %
Non-volatile:	2.0 % - 84.7 %	Average:	40.6 %

Table 5.1 Analysis of Sludge Samples

Sample No.	Equipment	Water Content %	Non-volatile Content %	Volatile Content %	Density kg/ m^3	Character	scal.reading at rotor speed 4	Hose length m	Suction depth	Comment
1	Calabrese	60.0	38.0	2.0	1'290	low$^-$	7	21	2.0	limit
2	Calabrese	89.0	4.6	6,4	1'042	low$^-$	9	18	1.5	"
3	Poole	62.8	33.8	3.4	1'260	low$^-$	2	13	3.0	"
4	Poole	81.5	9.9	8.6	1'086	low	16	13	1.5	"
5	Poole	87.6	4.9	7.5	1'046	low$^-$	5	13	1.5	numerous rags, bottles
6	Poole	85.0	5.0	10.0	1'051	med.	27	13	1.5	strenuous
8	Poole	82.5	9.3	8.2	1'081	low	10	13	1.5	limit
9	Poole	72.0	20.1	7.9	1'163	low	11	13	2.0	"
10	Poole	88.7	2.0	9.3	1'027	low$^-$	4	13	2.7	"
12	Poole	82.0	9.4	8.6	1'082	low	11	13	1.0	"
14	Poole	66.9	28.9	4.2	1'224	low$^-$	5	13	1.4	"
16	Poole	69.4	20.0	10.6	1'161	high	90	13	0.4	could not be removed
21	Poole	82.1	9.6	8.3	1'031	low	11	13	2.0	limit
22	Poole	86.4	5.0	7.7	1'033	low$^-$	5	13	2.0	"
23	Poole	54.0	41.7	4.3	1'323	low$^-$	4.5	13	1.4	"
24	Poole	50.0	43.4	6.6	1'338	med.	24	13	1.5	strenuous
25	Rolba	55.6	36.8	7.6	1'282	med.	19	14	1.2	between emptying
26	Brevac	18.1	79.7	2.2	1'989	med.	20	11	1.3	normal emptying
27	Brevac	13.0	84.7	2.3	2'159	high$^+$	-	11	1.3	limit
28	Brevac	39.7	58.6	3.2	1'574	low	8	44	2.0	normal emptying
29	Brevac	32.8	61.8	5.4	1'595	med.$^+$	43	44	1.8	"
30	Rolba	38.2	58.6	3,2	1'551	low$^+$	16	44	1.5	"
31	ALH	69.4	20.0	10,6	1'161	high	90	5	1.5	limit
34	Brevac	31.8	63.9	4.3	1'646	med.	28	11	1.8	normal emptying
35	Brevac	79.8	11.3	8.9	1'046	med.	26	11	1.8	"
36	Brevac	36.2	58.1	5.7	1'510	high$^-$	65	27	1.5	"
37	Brevac	14.2			2'061	high$^+$	-	11	3.2	limit
38	Brevac	dry sand				high$^+$	-	11	3.0	"
39	Brevac	30.1	65.9	4.0	1'676	med.$^+$	40	11	2.8	normal emtying
40	Rolba	73.9	14.9	11.2	1'104	high	90	6	2.0	limit
42	Rolba	58.8	32.5	8.7	1'230	med.$^+$	38	18	1.5	normal emtying
44	Rolba	33.7	62.3	4.0	1'640	med.$^+$	43	14	1.5	"
45	Rolba	45.8	46.9	7.3	1'582	med.$^+$	55	14	1.7	"
46	Rolba	39.6	54.4	6.0	1'522	med.$^+$	42	10	1.7	"
47	Rolba	43.5	52.6	3.9	1'496	low	11	10	1.8	"
48	Rolba	38.7	56.3	5.0	1'592	med.	16	14	3.0	limit
49	Rolba	25.9	71.3	2.8	1'712	med.$^+$	33	14	1.3	normal emtying
49b	Rolba	31.9	65.0	3.1	1'628	med.	18	14	1.3	"
50	Brevac	25.2	72.2	2.6	1'424	med.	23	64	1.5	"
51	Brevac	16.2	81.2	2.6	2'081	high$^+$	-	64	1.5	limit
52	Rolba	79.1	11.8	9.2	1'104	med.	42	6	1.5	normal emptying
53	Rolba	27.4	69.9	2.7	1'834	low$^+$	18	14	1.2	"
54	Rolba	29.4	66.5	4,1	1'756	med.$^+$	44	26	0.8	"
55	Rolba	33.6	61.4	5.0	1'688	high	59	6	1.4	limit
56	Rolba	70.6	19,6	9.8	1'256	med.$^+$	46	58	1.5	normal emtying
57	Rolba	67.1	23.6	9.3	1'260	med.$^+$	45	58	1.5	"
58	ALH	14.0	82.8	3.2	2'072	high$^+$	-	5	1.5	limit

Fig. 5.1 Flow Curve of one sample

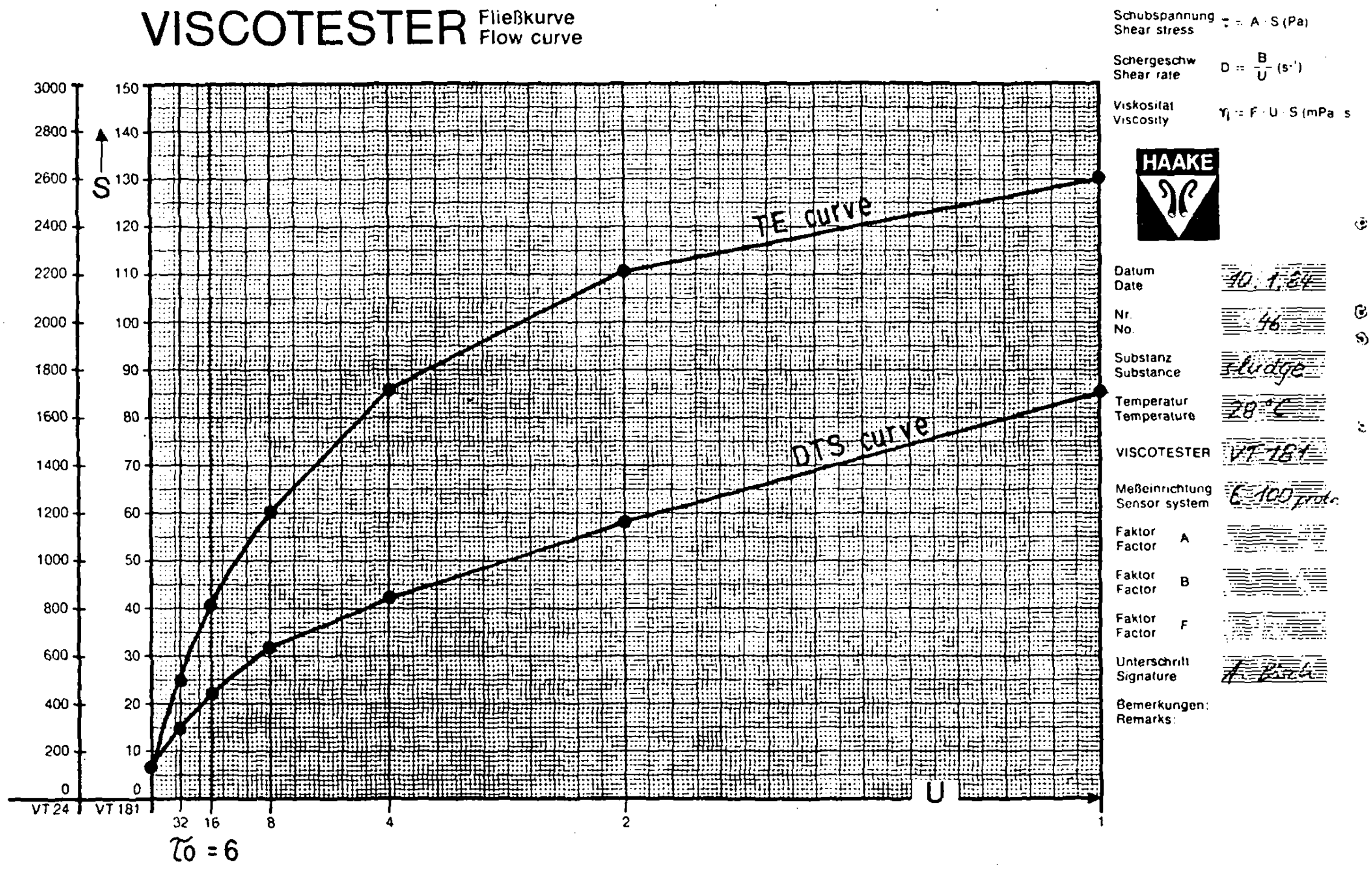
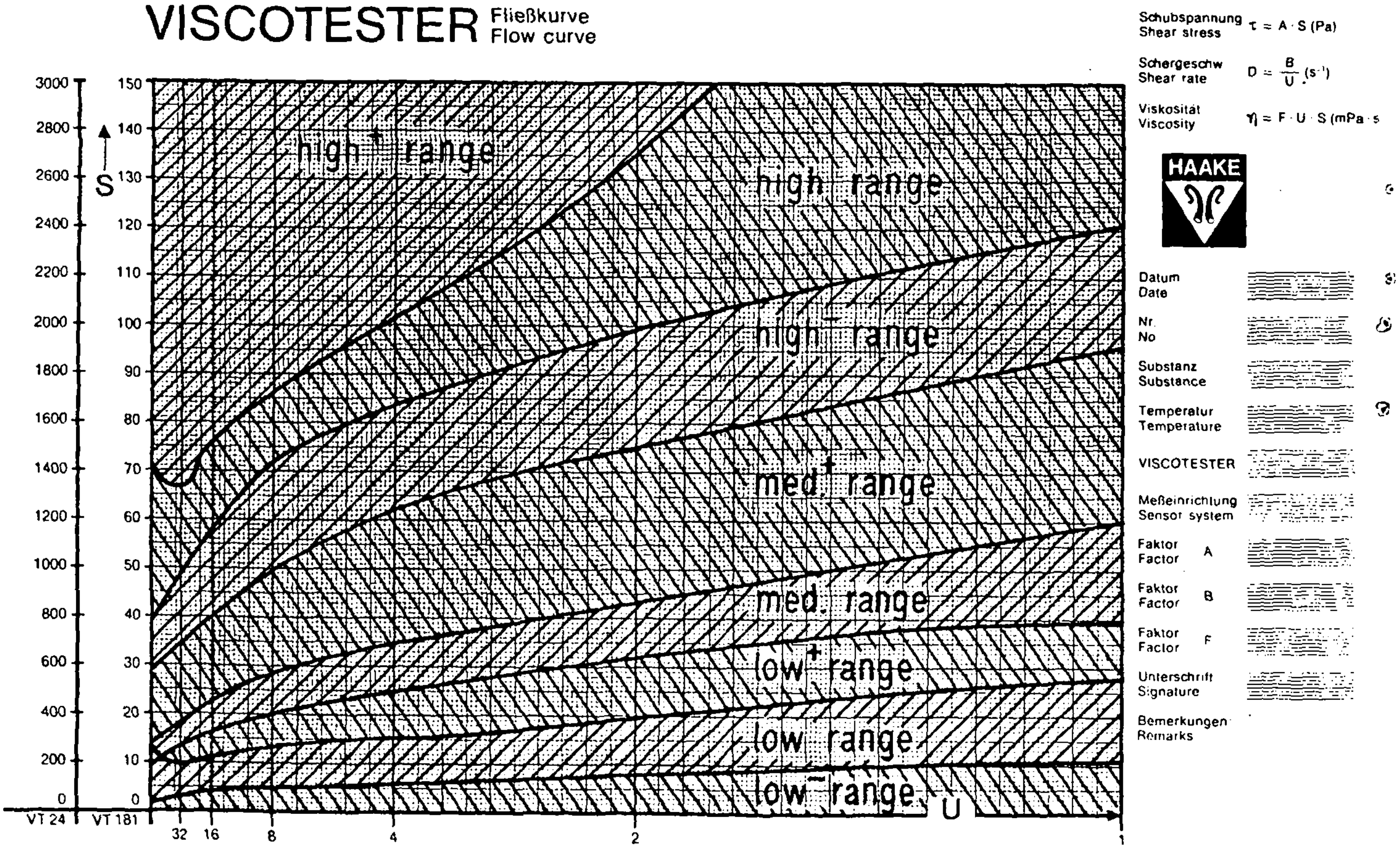


Fig. 5.2 Viscosity Ranges



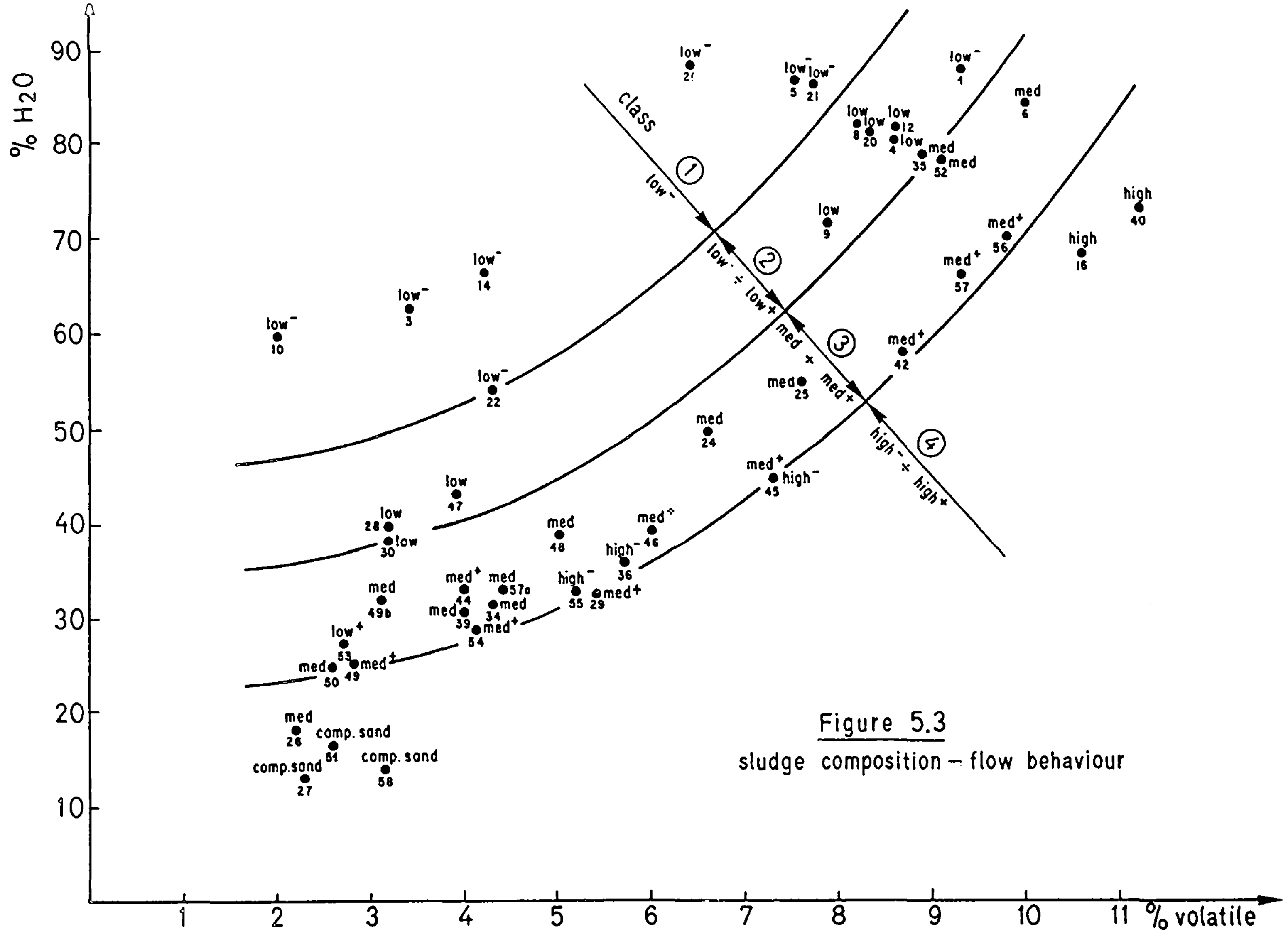


Figure 5.3

sludge composition – flow behaviour

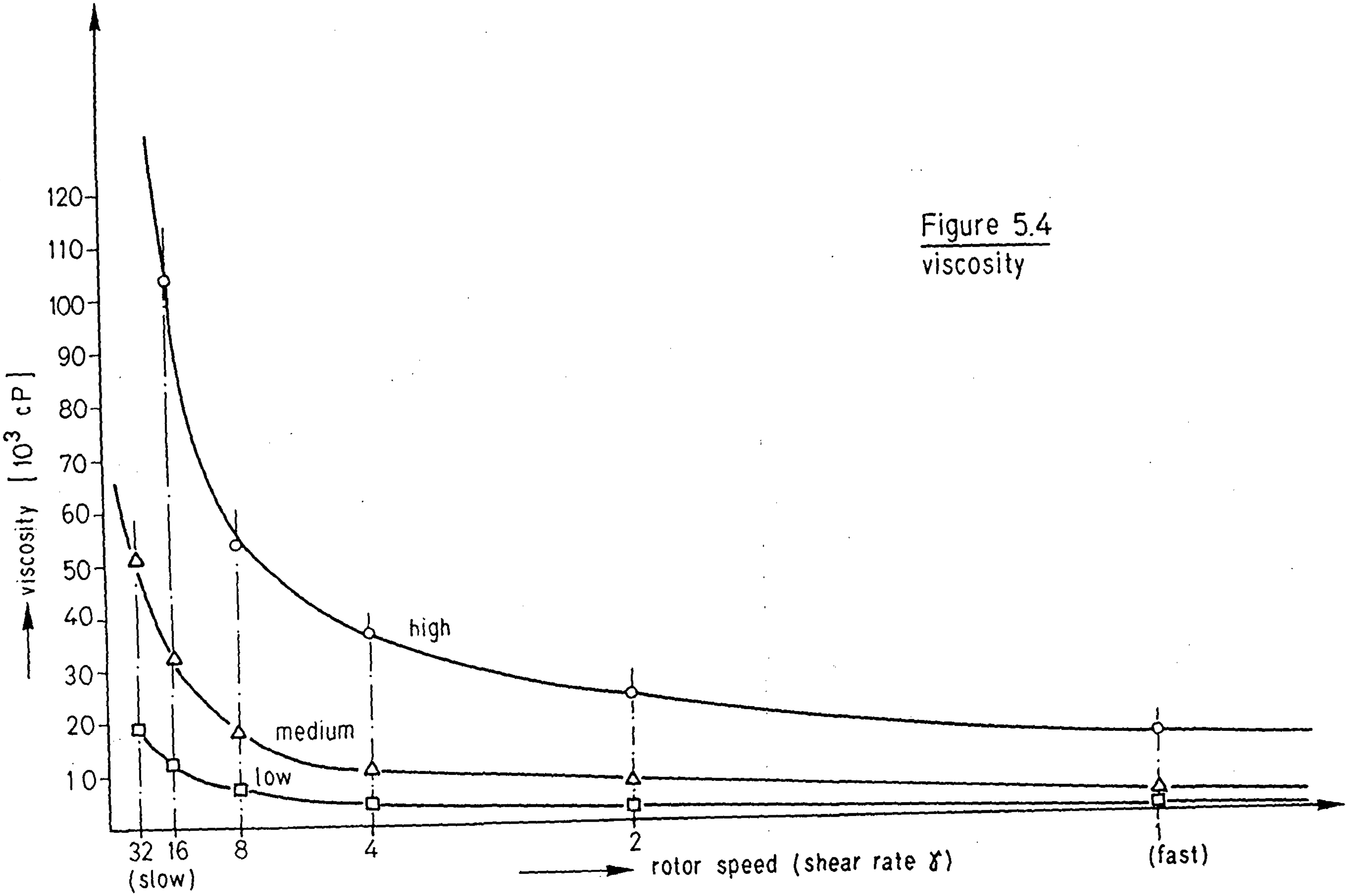


Figure 5.4
viscosity

6. WORK ON SITE

6.1 On Site with CALABRESE

a) ACCESS AND OPERATION

As the City Council of Dar es Salaam naturally only services pit latrines which can be reached with the local vacuum tanker, the problem of inaccessible latrines was not experienced during the 10-day trip with the crew in Dar es Salaam. During discussions with the City Council, however, it was pointed out that many pit latrines were not accessible for the local vacuum trucks and that distances separating truck and pit up to 100 m and more were experienced. As these pits have not been emptied for years or have never been emptied at all and were about to overflow, the City Council was very concerned to test remote emptying systems like ALH in Dar es Salaam.

In addition to the distance problem, the latrines were often located in the backyards and the only way to reach the pits was by setting up the sludge pipes through the house (see photo No. 2, page 36). While dismantling the pipes after the pit was emptied, the house was unavoidably contaminated with sludge. This is another indication of the need to develop remote systems, as only air pipes would need to pass the house. The question of how well full drums can be transported through houses with a hand trolley, however, remains to be tested on the spot. Access to the pit contents was generally through the squat-hole since most latrines were old, conventional, unimproved single-pit latrines.

Emptying work on pits containing heavy sludges was usually very tiring and difficult. As the unit works on the principle of a vacuum system, it was restricted to raising low-viscosity sludge only from a 1.5 m deep pit and liquid only from a 3 m pit (see Table 11.2 on page 71). In order to remove some sludge, the crew tried to liquify it first by blowing air into the pit. This, however, is very dirty work as the liquified sludge sprays everywhere and contaminates the crew who work without overalls and gloves and are therefore exposed to serious health hazards. This hazard could be avoided if the vacuum pump were powerful enough to transport the sludge.

The grey water from the public wash stands, usually located near the latrines, was emptied easily (liquid only).

On Site with CALABRESE

Photo No. 1: Manoeuvering CALABRESE to the sludge disposal site

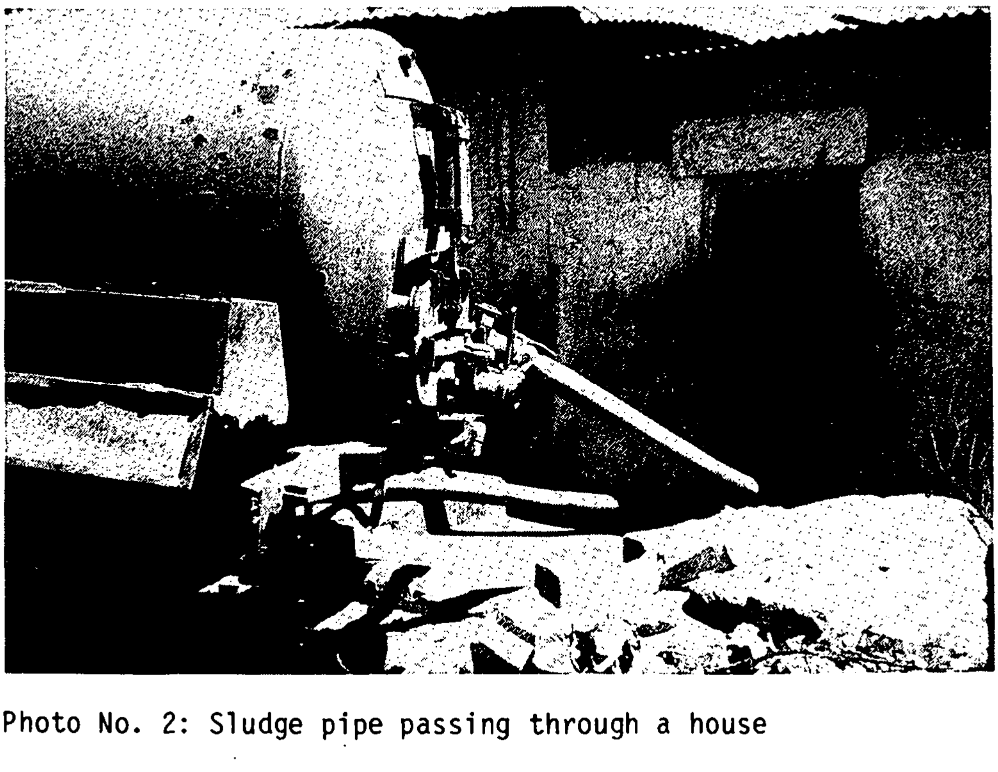


Photo No. 2: Sludge pipe passing through a house

b) SUCTION PERFORMANCE

As the CALABRESE tanker is equipped with almost the same-sized vacuum pump as that of the POOLE tanker, the performance of both systems is discussed in section 6.2. The main problem was found to be weakness of the pump. In addition, it failed frequently because of water and solids being sucked into it during pit emptying. This problem could be overcome by protecting the pump intake with an air filter unit. This, however, calls for regular maintenance and occasional filter replacement. Since proper maintenance cannot be guaranteed in most developing countries, and often no funds are available for spares, a good solution would be the use of a pump type less susceptible to damage by solids (e.g. liquid ring vacuum pump, see BREVAC, section 3.4, page 20). Another approach to the problem would be the combination of a sliding vane vacuum pump with a large water and solids separator which could be drained every evening by a valve (see ROLBA, section 3.3. page 16).

6.2 On Site with POOLE

a) ACCESS AND OPERATION

In contrast to Dar es Salaam, access conditions in Gaborone were very good (see section 1.3, page 4). As a result, the large-sized POOLE tanker (7.3 by 2.4 m) could be driven very close to the pits except in squatter areas. In almost all cases the tanker could be parked closer than 10 m to the latrine pit. Since POOLE is equipped with a 15 m long hose wrapped around the tank, no hoses had to be coupled together. Thus, the setting-up time was short and the working conditions comparatively easy. The disadvantage of this 'one hose system', however, is shown in the friction loss remaining constant along the 15 m hose, although the actual distance separating truck and pit may be less than the whole hose length.

The average setting-up time was 3 minutes and the time for dismantling and washing-down was approximately 5 minutes. Single-pit latrines with a capacity of 0.6 m^3 could be emptied in about 6 to 9 minutes, and a 1 m^3 septic tank in 5 to 7 minutes. It must be stressed, however, that only liquid and thin sludge with a viscosity range up to low^+ could be removed (see Table 11.2, page 71) which leaves the pits partially full of thicker sludge.

Access to the pit contents for all unimproved single-pit latrines and VIP latrines was through the squat-hole. This was not found to be a serious problem as the average-sized squat-hole was 200 mm wide, but the amount of sludge that could be removed was reduced because parts of the pit were inaccessible.

b) SUCTION PERFORMANCE (CALABRESE AND POOLE)

Both tankers (CALABRESE and POOLE) work on the principle of a vacuum system and are therefore restricted to raising low viscosity sludge and liquid only. Thicker sludge has to be removed by the application of the plug drag method, but as the airflow rates of the vacuum pumps used are too low to haul the free flowing air as well as the volume of the removed sludge, this method is not feasible for either tanker. With POOLE it takes at least 5 minutes to create a vacuum of 0.5 bar in the 7000 ℓ tank and this quickly falls to 0.2 bar as soon as the hose inlet is removed from the sludge. It is clearly uneconomic to operate a vacuum tanker as a plug drag system if it takes several minutes to create a vacuum between each up and down movement.

In addition to the low airflow, reduced vacuum heads caused by clogged pump air filters were observed. For instance the heavy resistance of the dirty paper filter unit used by POOLE (see photo No. 3, page 39), reduced the vacuum head from 0.67 (max.) to 0.4 bar. This is equivalent to a 4 m static head of water. The top of the delivery pipe in the slurry tank is about 2.5 m above ground level, which means that the maximum depth from which water can be raised into the tank is 1.5 m below ground level. As sludge has a higher density than water, a further decrease in the suction depth will occur. For a sludge with a density of 1'200 kg/m^3, the remaining suction depth below ground level drops to 0.8 m. This often leads the crew to erroneous assumptions, i.e. wrongly blaming a blocked suction hose for failing to pump sludge from a 1.5 m deep pit. This causes further embarrassment as the mechanics then check the suction hose for a blockage which does not exist. The friction loss along the hoses, which further reduces the effective suction head on the pit, has not been taken into consideration in this calculation.

During tests with the POOLE, it was also experienced that the auxiliary engine driving the vacuum pump did not perform the correct pump rotor speed of 1450 rpm. After testing, only 920 to 1100 rpm were measured which, of course, further reduced the suction power of the already

On Site with POOLE

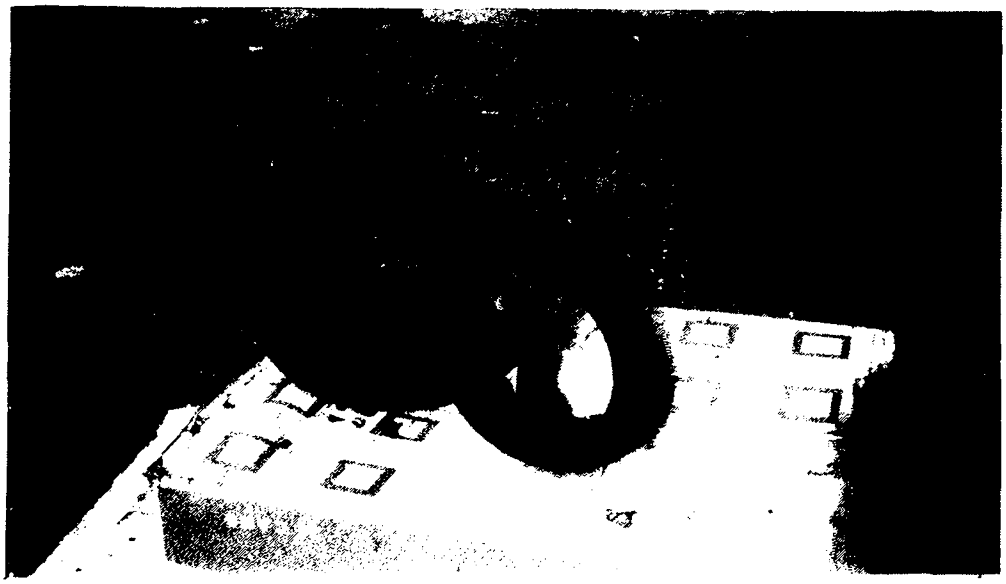


Photo No. 3: Completely clogged pump air filter after two weeks' use

Photo No. 4:

Back-staged vacuum pump driven by the auxiliary diesel engine small pump by about 25 %. This, together with the clogged pump air filter, caused very long tank-evacuating times. The time taken to create a vacuum head of 0.5 bar in the 7000 ℓ POOLE tank under these bad conditions was 15 min.

6.3 On Site with ROLBA

a) ACCESS AND OPERATION

Little difficulties in getting access to the latrines were occasionally experienced with the large-sized ROLBA tanker (see photo No.5,page 41). As the crew preferred to use the 16 m by 100 mm hoses rather than the 40 m by 75 mm hoses - mainly because the 75 mm hoses were more susceptible to blockage - every attempt was made to bring the tanker as close to the pit as possible. Obstructions such as trees, fences, laundry ropes or piles of bricks were occasionally damaged which caused arguments between the crew and plot holders.

Setting-up time was generally between 2 and 6 minutes. The emptying time for conventional single-pit latrines with a capacity of about 0.6 m^3 took from 4 to 8 minutes and for the 1 m^3 septic tanks 3 to 5 minutes. Dismantling and washing-down time was approximately 2 minutes longer than setting-up times since the hoses were cleaned with the high pressure washwater forced through them from the 1000 ℓ tank. This washwater facility was very much appreciated as it released the crew from having to carry water in tubs.

There was a considerable increase in the time spent emptying the double-pit latrines when using either the ROLBA or BREVAC tankers. It must be noted, however, that the trials were performed on unlined double-pit latrines, as the new, lined REC II latrines were not yet ready for emptying. The average time taken to empty these double-pit latrines was half an hour per chamber. The pit contents were very dense since they consisted of a mixture of excreta-derived material and sandy soil, with the latter predominating due to the pits being on the verge of collapse b/. The analysis of the driest sample collected with ROLBA

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b/ This clearly indicates the need for proper lining of the pits in blockwork or brickwork. The contents of properly lined pits are likely to be less dense and as a result less powerful, less expensive and more easily-maintained tankers would be adequate.

On Site with ROLBA

Photo No. 5: Access prevented by trees

Photo No. 6:

Work with aluminium nozzle and high pressure washwater through removable slabs on a double pit latrine showed a composition of 25.9 % water, 71.3 % sand and only 2.8 % organic content. Because of the very high sand content, the density was 1'712 kg/m^3 and the viscosity was measured in the medium$^+$ range (Sample number 49 in Table 5.1, page 31).

b) SUCTION PERFORMANCE

The airflow rate of 17 m^3/min. created by the pump was too low to permit work with the constant air drag system. Successful results in pumping high viscosity sludge were nevertheless achieved by applying the plug drag method. This device proved to work well as the airflow was sufficient to create quickly a new vacuum in the 6 m^3 slurry tank between each up and down movement. It was experienced, however, that this method required a great deal of effort from the crew who, when removing heavy sludge in temperatures exceeding 35°C, tired easily, and were inclined to stop work before the pit was entirely emptied.

To relieve empting work, ROLBA's design includes the use of the high pressure washwater which is forced into the pits at the same time as the suction hose removes the liquified sludge. This system will work well as long as access to the pits permits the use of both the suction hose and the high-pressure water hose simultaneously - for instance in the case of a double-pit latrine with its removable slabs (see photo No. 6, page 41). In latrines where the only access to the pit is through the squat-hole (200 mm diameter), it is impossible to use both hoses at once. Apart from this problem, this method cannot be recommended for use in countries where water supplies are severely restricted. The water in the tank could be replaced by treated sewage effluents but this might encourage the crew, deprived of clean water to wash their hands in, to use the effluents for this purpose and so create severe health hazards

In addition to the usual pit emptying work, long hose tests were carried out for comparison with the ALH equipment as described in chapter 7, page 51.

6.4 On Site with BREVAC

a) ACCESS AND OPERATION

The first problem encountered was the limited space to accommodate the 4-man crew on the BREVAC. Since there is no platform at the rear to provide accommodation for the additional crew members, the workers found themselves squashed in the cab. Whenever tests with BREVAC were carried out, one crew member had to travel in a van accompanying the tanker.

As the BREVAC tanker appears to be smaller than the ROLBA and POOLE, it could be manoeuvred next to the pits more easily, even in squatter areas. To avoid the nuisance of handling several 3 m hoses, BREVAC was equipped experimentally with a 10 m long flexible plastic hose carried wrapped around the tank. About 90 % of all latrines could be reached with this single hose. Additional 3 m hoses were attached to it, however, when the distance to the latrine was more than 10 m. This was found to be a very practical approach to the situation encountered in Gaborone. It must be emphasized, however, that conditions will vary with different environments. For instance, the best hose kit fitting conditions in Dar es Salaam may consist of several 10 m by 100 mm hoses.

When using the single 10 m hose, the setting-up time dropped to somewhere between 1 to 2 minutes, whereas operating with several 3 m hoses, the setting-up time was between 3 and 5 minutes. Emptying time for the conventional single-pit latrine with its sludge content of about 0.6 m^3 took 4 to 7 minutes, and for the 1 m^3 septic tanks, approximately 3 to 4 minutes. Dismantling and washing-down time was about 2 minutes longer than setting-up time (Compare with ROLBA page 40). A slight increase in emptying time occurred when the hose inlet was frequently blocked by bulky material (see photo No. 8, page 45). This time increase was mainly due to the handwheel-operated suction valve, which of course takes time to open and close. This valve has now been equipped with a lever and is much quicker to operate.

The high pressure washwater facility was of course very much appreciated. The clean water tank, however, only contains 200 ℓ. This limited the available continuous cleaning time to 5 minutes as the clean water pump delivers 40 ℓ/min. To have enough water for a working day, the container had to be refilled twice and, because of the awkwardly situated inlet, the refilling time taken was 15 minutes.

At the beginning of the tests, problems with overfilling the slurry tank were experienced as BREVAC was not equipped with a level gauge. The only way to check the level was to open the hatch on top of the tank. This was often neglected and the crew continued to fill the tank until the level control valve stopped the airflow. The valve, however, closed too late, and a 'gulp' of sludge was sucked into the vacuum pump each time, thereby contaminating the service liquid which then had to be changed more frequently than suggested in the maintenance manual (once a week). These problems have also been solved by installing a floating ball gauge which indicates the sludge level inside the tank.

To investigate the possibility of using a suction tanker in an area where access to the latrine is more difficult, the BREVAC was driven to Lobatse, a town about 75 km from Gaborone (see map on page 6). Little difficulty was experienced in manoeuvring the BREVAC along the steep and narrow paths of Peleng, a district of Lobatse (see photo No.7, page 45).

b) SUCTION PERFORMANCE

As noted in section 3.4, the high performance liquid ring vacuum pump enables the tanker to be used both as a vacuum system and a combination between the plug drag and the constant air drag method. The airflow rate of 26 m^3/min, however, is still too small to operate in a constant air drag method, as such systems utilize airflow rates of 60 up to 100 m^3/min. and more (fan type).

The suction pull was very powerful and could penetrate even compact dry sand with a water content of only 13 % (sample No. 27). To remove sand and heavy sludge more easily, a 2 m long air bleed nozzle was attached to the hose inlet. In single-pit latrines, this limited sludge removal to a depth of 2 m because the quick coupling on the nozzle's upper end did not go through the 200 mm diameter squat-hole.

Although the BREVAC could remove even compact sandy material, mostly found in the unlined double-pit latrines in the area of Old Naledi, emptying time for these pits took half an hour or more per pit. It was also very tiring because a combination of air drag and plug drag method had to be used.

The additional long hose tests carried out with BREVAC are described in chapter 7, page 51.

On Site with BREVAC

Photo No. 7: Manoeuvring in narrow paths in the area of Pelang

Photo No. 8: Hose inlet blocked by bottles

6.5 On Site with ALH Emptying Equipment

a) ACCESS AND OPERATION

Three different methods have been considered for working with the ALH system:

1. In addition to the trailer, a large collection lorry equipped with a crane to hoist the full drums onto the lorry would pass all the collection points, loading the drums and transporting them to a disposal site. The ALH trailer would be pulled by a tractor;

2. A small lorry would pull the trailer unit as well as transport about 18 drums (including a clean water drum);

3. The trailer unit would work together with a suction tanker. The full drums would be transported with the hand trolley from the pits back to the tanker, which would then suck the drums' contents into the slurry tank.

As no lorry with a crane was available, and no convenient method was found for emptying full drums at the sludge disposal site, it quickly became apparent that the only reasonable solution would be to work with a suction tanker. This matter was discussed with ALH, and it was agreed that future ALH equipment would consist of a suction tanker equipped with holding facilities for three drums, a hand trolley and a reel for air hoses (see Appendix VI).
This equipment would include the advantage of both a suction tanker and a remote system as it would work like a normal tanker provided access to the latrine was possible. The drums would only by applied when access was difficult.

In order to simulate this system, a local POOLE tanker was modified with:

- facilities to carry a drum;

- a 75 mm air hose with ALH coupling joints, to connect the slurry tank with the ALH pump;

- a 3 m by 100 mm hose to discharge the full drums into the slurry tank

On Site with ALH Emptying Equipment

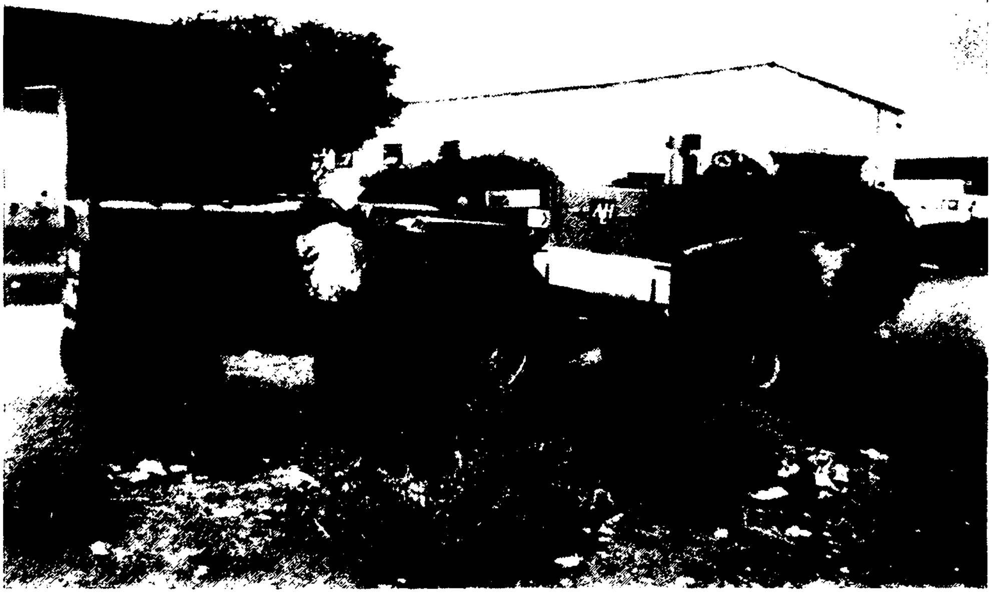


Photo No. 9: ALH trailer pulled by a tractor

Photo No. 10

Drum overfilling problems

Before the work was finally started, the following alterations to the ALH equipment had to be carried out:

- replacing of the original 100 mm suction hose, which had collapsed due to the high temperature, with a local 100 mm plastic hose

- repairing of the alternator at the Town Council's workshop, as it was not charging

- fitting the top hat section with a rubber seal.

After problems had been encountered loading everything on the trailer (the wash-water drum with hand pump could not be accommodated since it was supposed to be transported by a collection lorry), the top hat section fell off during transport, and was badly dented.

During operations with the system it quickly became obvious that the dip stick designed as a 'level indicator' failed in its purpose. As a result, the drums overfilled and, when the top hat section was lifted from the drum, the sludge accumulated in the top hat section splashed onto the ground (see photo No. 10, page 47). The same problem was observed during further tests with another kind of dip stick and it was finally decided to redesign the top hat section. In addition to the overfilling problems, difficulties in transporting the full drums with the hand trolley over sandy ground were experienced, and setting-up times up to 30 min and more were measured. Based on the field experience it was agreed among the parties involved that remote systems call for further investigations. Guidelines for the remote unit are given in section 10.2, page 64.

b) SUCTION PERFORMANCE

Unfortunately, because of the above mentioned difficulties, insufficient tests were carried out to be able to draw conclusions in pumping limits. Two samples, however, were taken for analysis and viscometer test. The result showed a viscosity in the high range and, in the case of the second sample, compact sand with a water content of only 14 %. Both samples, however, were taken from a 1.5 m deep pit and it is still unknown what kind of material can be lifted with the ALH equipment from a 3 m deep pit.

6.6 On Site with the BUMI Hand Pump

During work with the Bumi pump, the following main problems were encountered:

- As the suction hose measures only 50 mm in diameter and the pits are full of bulky rubbish, blockages of the hose inlet occurred very often. As a result, emptying work became quite tedious. In addition, small objects jammed in the pump's diaphragm, which then had to be cleared by pumping water before sludge could be pumped again;

- Although the pump was cleaned by sucking water through it after emptying work, sludge remained in the pump body, thereby causing the diaphragms to stick together when drying overnight. Before the pump could be started in the morning it had to be washed out first;

- The sludge was pumped into ALH drums and caused the same drum handling problems as described in section 6.5. A useful addition to the BUMI pump would be a small trailer-mounted slurry tank to transport the pumped sludge to the dumping site;

- As BUMI is operated by two 2 m long extension bars, the pump location should measure at least 4 m in width (see photo No. 11, page 50);

- Pumping is quite hard work in temperatures exceeding 35° C and therefore, the crew members tend to stop work before the pits are entirely emptied;

- Only water and very thin sludge could be removed, and even this took an unreasonable length of time. The time required to fill a 200 ℓ drum with liquid from a pit was about 30 minutes.

The BUMI pump was recognized as good for pumping water, or very thin sludge. However, experience in Botswana suggests that it is not very suitable for pumping sludge, especially when dealing with pit latrines that contain a lot of rubbish.

On Site with BUMI Hand Pump

Photo No. 11: BUMI pump fitted in the back of a van and operated by two men

7. LONG HOSE TESTS

In addition to the usual pit desludging trials, long hose tests were carried out (see photo No. 12, page 54) in order to compare suction tankers with the ALH remote system which was designed especially for use over long suction distances.

7.1 Long Hose Tests with ROLBA and BREVAC in Gaborone

Since neither ROLBA nor BREVAC were equipped with hoses to cover suction distances of more than 50 m or so, all the available 100 mm hoses were used, amounting to a length of 70 m. The loading of all the pipes and hoses onto the tankers was the first problem encountered. Whilst the ROLBA tanker could transport the hoses, there was not enough space on the BREVAC and therefore, 16 m had to be transported in a van.

To conduct the trials, collapsed double-pit latrines with their very compact sandy contents were chosen, and the tankers were parked some 70 m away from the pits. The test sequence applied was the same for both tankers, i.e. to start sucking heavy sludge through the 70 m pipe and then gradually to reduce the length, piece by piece, until the suction pull on the hose inlet was strong enough to remove dense sludge. For each tanker, the same procedure was applied twice, ending up with a maximum length of 64 m for BREVAC and 58 m for ROLBA.

The following main problems were observed for both tankers:

1. During operation, significant mud layers settling in the pipes and hoses were observed. To clean the pipe, water was sucked through the hoses every 5 to 10 minutes.

2. Hose blockages caused by bulky materials such as bottles, rags and stones occurred frequently. Locating the blockage is a very difficult, unpleasant and time-consuming operation, which calls for systematic uncoupling of the hoses until the obstruction is found. The quickest strategy to find the blockage (uncoupling of the hoses at their mid-point to find out which half is blocked and then moving to the middle of the blocked half until the blockage is discovered) was not fully understood by the tanker crew. This caused them embarrassment and was also very time-consuming. It is very important

that blockages be found with the minimum number of hose uncouplings, since sludge pours from each opened joint and contaminates areas where children play. In Dar es Salaam, where access to many latrines is only possible through the house, the clearing of blockages in this way would create unacceptable health risks.

3. Since BREVAC's clean water hose is only 16 m long and ROLBA's 27 m long, the pits could not be reached. Instead, the plot-holders had to provide all the water for the regular rinsing of the pipes, as well as for cleaning the hoses and the latrine after the work had been done.

4. It should be possible for the hose operator to break the vacuum as soon as large items block the hose inlet. However, communication between the hose operator and the operator at the suction valve on the tanker is often difficult as they are separated by up to 70 m distance and therefore out of earshot and often also unable to see each other.

5. As the long pipe consists of several 3 and 4 m hose segments, the setting-up time for a 70 m pipe was 15 minutes and the dismantling and washing-down time was 20 minutes.

The field experience gained from the long hose tests suggested that a remote system like ALH should only be used when suction distances are in excess of 60 m.

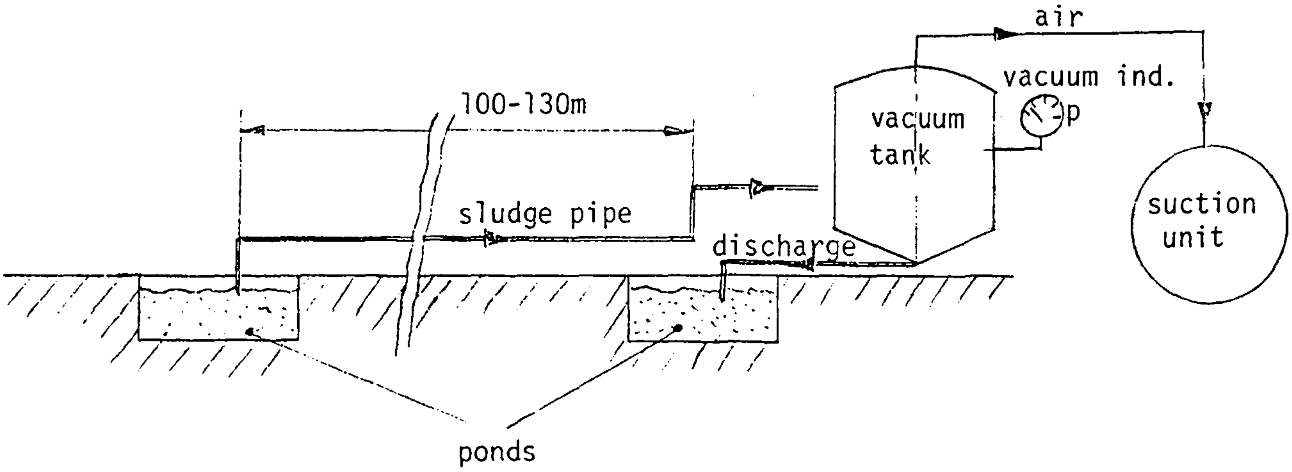
7.2 Long Hose Tests with Liquid Ring Vacuum Pump in Sheffield, U.K.

To measure the pressure drop in pipelines over distances of more than 60 m, additional tests, using air only, thin sludges and water were carried out in Sheffield, England. The equipment loaned for the tests by Airload Engineering Ltd. consisted of a liquid ring vacuum pump, similar to that fitted on the BREVAC tanker, and a tank mounted on a truck. The equipment was arranged for the trials as shown in Fig. 7.1, page 53.

The experimental procedure was to measure the pressure drop along the suction pipe by recording the gauge reading of the vacuum in the tank. Measurements were made when transporting air only, water and two types of sludge, at three different pump speeds. The tests with water and sludge were carried aut with no air bleed (vacuum system) and also with an air bleed nozzle (pneumatic conveying).

The tests demonstrated that emptying latrine pits containing low-viscosity sludge over distances in excess of 100 m is perfectly feasible by a pneumatic conveying system with an air bleed nozzle. Without an air bleed, the friction losses were found to be up to 0.4 bar in a 100 m by 100 mm, hose which restricts the maximum static head over which the sludge can be raised to approximately 4 m. This will be inadequate when dealing with pits deeper than approximatelly 2 m.

Figure 7.1 Test Arrangements in Sheffield, U.K.



The results obtained with air only in 100 m and 120 m by 100 mm hoses have enabled a calculation of the friction losses in a 75 mm hose. The maximum practical distance for a remote system was found to be 150 m, which will give a head loss of 0.2 bar.

Long Hose Tests in Gaborone

Photo No. 12: View of the suction tanker

Photo No. 13: View of latrine

8. WORK AT THE SLUDGE DISPOSAL SITE

As both tankers, BREVAC as well as ROLBA, were capable of removing very viscous and sandy sludges, some problems were experienced when discharging the full tanks. Although the sludge was discharged under pressure (see photo No. 14, page 57), outlet blockages caused by rags and rubbish occurred frequently (see photo No. 19, page 59). This was mainly due to the discharge valves being only 100 mm in diameter. To loosen the obstructions, the load/discharge valve was changed alternately from suction to pressure position. This procedure, however, was recog- nized as quite tiring as the valve had to be changed 16 times after emptying dry pits only. In addition, heavy material such as sand and stones did not flow out with the liquid but settled to the bottom of the tank. This called for regular tank cleaning (once a week) which is described below.

8.1 Tank Cleaning

a) ROLBA

For tank cleaning, a worker wearing a gas mask and boots enters the tank through the top-mounted hatch (see photo No. 16, page 58). Equipped with a shovel, he scoops the settled material through the small rear door (see photo No. 15, page 57). He also has to cut off the rags entangled in the ball gauge and level control valve. It must be emphasized that, although the man wears a gas mask, this job is very dangerous, particularly as the GTC crew is unaware of the hazards, and has been seen climbing into the tank without gas masks (see photo No. 17, page 58). Gas-related accidents often claim several casualties as other people go to the rescue of the original victim. Needless to say, the worker gets completely contaminated by the sludge, which causes further health problems.

While the inside of the tank is being cleaned, the washwater tank is refilled and the driver checks the engine and washes the truck. This whole procedure takes approximately one hour.

b) BREVAC

In contrast to ROLBA, BREVAC's tank was much easier to clean. As the work is carried out by opening the rear door and tipping the tank to a steep angle (see photo No. 18, page 59), the workers do not come into contact with the sludge. The settled material slides out and the tank can be hosed down with the washwater. To wash the tank properly, however, the whole content of the washwater tank (200 litres) is required and therefore it has to be refilled before and after cleaning of the slurry tank. The time taken for cleaning the tank is 30 minutes.

c) POOLE

Such tank cleaning work was not necessary for the POOLE tanker, as its performance is restricted to handling only liquid and thin sludge which flows out easily. In addition, the tanker is equipped with a large 240 mm diameter outlet pipe with a flap valve, hence blockages did not occur so often as with the ROLBA and BREVAC.

8.2 ALH Slurry Drum Emptying

As already mentioned in section 6.5, the full drums were emptied by a POOLE tanker. The vacuum in the tank was created by connecting the tank via a 75 mm hose with the ALH pump.

Until more experience is gained and suitable equipment developed, emptying full slurry drums at the dumping site is still a difficult undertaking.

From the experience gained during discharge, immediate recommendations for tanker designs could be made and are described in chapter 10, page 62.

ROLBA's Tank Cleaning

Photo No. 14: Discharging the tank under pressure

Photo No. 15:

Tank cleaning by shovelling the settled material through the rear door

ROLBA's Tank Cleaning

Photo No. 16:

Worker equipped with a gas mask climbing into the tank to clean it

Photo No. 17:

Dangerous tank cleaning work without gas masks

BREVAC's Tank Cleaning

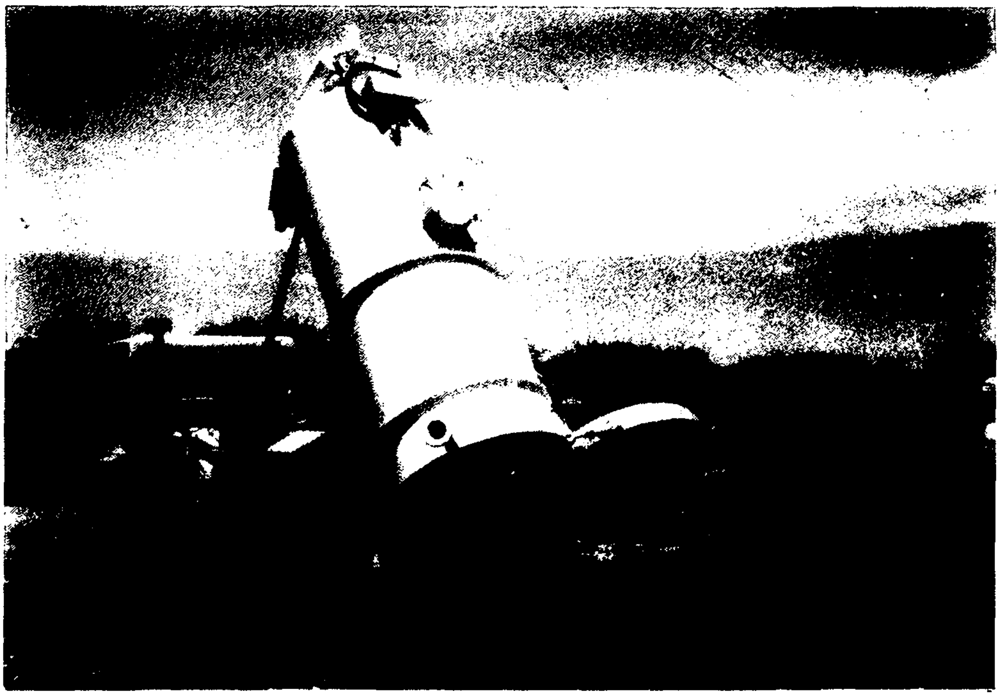


Photo No. 18: Tank cleaning by means of a hydraulic tipping cylinder

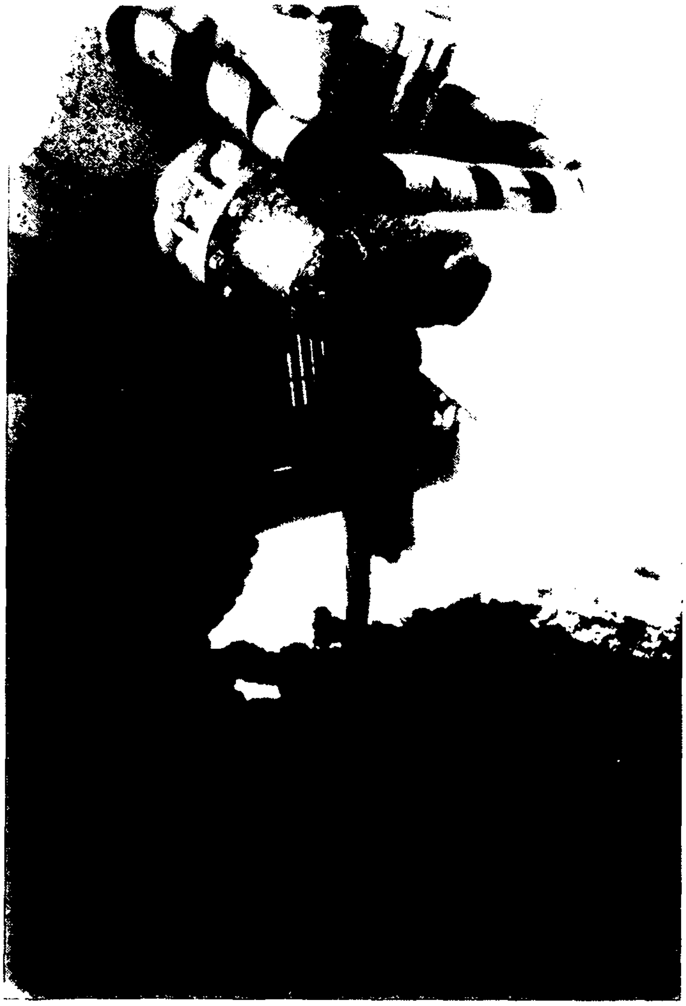


Photo No. 19:

Outlet blocked by rags

9. MAINTENANCE

As outlined in section 1.3, the Gaborone Town Council's workshop is quite well organized and almost all spare parts are obtainable from South Africa, although with some delays.

The ROLBA tanker was maintained by the Scania agent in Gaborone. Being responsible for ROLBA, Ragn Seels engaged the Scania agent in a contract, obliging them to carry out all routine maintenance work according to the handbook. Therefore, the Scania agent sent a mechanic to the Council yard every second day to check the entire equipment and to oil all the important parts. Fortnightly, the ROLBA tanker was taken to the Scania workshop for maintenance.

BREVAC was maintained by the Gaborone Town Council's workshops and BRE has provided a stock of spare parts for the suction system. BRE also contracted Airload Engineering, U.K, to provide training for Town Council staff in the use and maintenance of BREVAC.

Because of this difference in servicing and the fact that the equipment was only in operation for 4 months, it is quite difficult to compare the upkeep of the ROLBA tanker with that of the BREVAC tanker and the ALH equipment. The main service work required during the four-month period for the different equipment was as follows:

ROLBA:
Chassis and engine:
Normal engine and chassis service according to the SCANIA manual; greasing of all points and changing of the engine oil every two weeks (changing of oil filter each 5000 km).

Superstructure:
1. cleaning of the vacuum pump by sucking diesel oil through the pump fortnightly;
2. removing and cleaning of washwater filter fortnightly;
3. greasing of the power take-off shafts weekly and the whole unit fortnightly;
4. cleaning of the safety guard valve inside the tank weekly.

For the daily and weekly checks see the Inspection sheet on Appendix VII, page 1.

BREVAC:

Chassis and engine:

Normal engine and chassis service according to the FORD manual, whereby the engine oil, oil filter and fuel filter should be changed every 7500 kilometers.

Superstructure:

1. draining of the vacuum pump water tank (service liquid) and removing and cleaning of the vacuum pump water filter weekly;
2. removing and cleaning of washwater filter weekly;
3. greasing of rear door handweels, tank pivots and tipping ram pivots at every 7500 km service
4. dismantling and greasing load/discharge control valve approximately every 6 weeks.

For daily and weekly maintenance checks see the Operator's Manual on Appendix VII, page 2.

ALH REMOTE SYSTEM:

Due to the problems caused by drum overfilling, the ALH equipment was been only run a few times during the test period and did not need any maintenance. The expected service, however, is described on the Maintenance-Instruction sheet in Appendix VII, page 3.

Of course, both organizations, BRE and Ragn Sells, were anxious to keep their machines running well during the tests. It must also be stressed that the tests were conducted under the supervision of an IRCWD engineer who could advise the mechanic when problems occurred. It is therefore possible that such machines may fail in other Third World environments because of the lack of maintenance or when no experienced engineer is available to advise the mechanics. One of the tankers, BREVAC, is therefore still in Gaborone to undergo a long-term testing, supervised by a member of the Ministry of Local Government and Lands. According to the latest information, BREVAC's suction unit is still working well (after one year), but some problems in getting spare parts for the Ford chassis were reported from Gaborone.

10. PROPOSED SPECIFICATION

During the final day's discussion with all the participants of the workshop in Gaborone, and in the light of the performance of the equipment tested and general experience, the following specifications for sludge removing devices for Third World countries were proposed.

10.1 Specification for Suction Tankers

a) VACUUM PUMPS

In general, three different types of vacuum pumps can be used for evacuating slurry tanks as described in Appendix IV. The most common types are the liquid ring and sliding vane pumps which should be modified as follows:
liquid ring vacuum pump for high capacity tankers (pneumatic conveying) and sliding vane pump for low capacity tankers (vacuum system).

b) PUMP DRIVE

It is usually better for the vacuum pump to be powered by the truck engine rather than by an auxiliary engine. The pump can be driven by a power take-off (PTO) shaft from the standard truck gearbox but the power that can be transmitted in this way is limited to 22-25 kW, which is adequate for small and medium-sized pumps. The option of powering larger pumps by PTO from special gearboxes which can transmit the full engine power, is not recommended because of the cost of the gearbox and the availability of spares.
The alternative for powering heavy duty pumps is to use hydraulic transmission. This has the great advantage that other units such as tank tipping cylinders or water pumps can be driven by the same hydraulic circuit.

c) SLURRY TANK

To facilitate tank cleaning and maintenance work and for safety, all tanks should have a fully-opening rear door. Tankers fitted with vacuum pumps capable of shifting heavy sludge should also have the capability of cleaning the tank mechanically (tank tipping cylinder or pushing plate). A reliable tank level indicator and a level control valve to break the vacuum when the tank is full, should also be incorporated. A hatch on the top should provide access to the interior of the tank. To prevent overpressure when discharging, a pressure-relief valve should also be fitted to the tank.

d) CLEAN WATER TANK

The clean water tank should have a capacity of at least 500 ℓ or, in the case of big tankers, 10 % of the slurry tank capacity.

A small multistage centrifugal water pump creating a pressure head of about 7 bar should be attached to the chassis. A 20 mm diameter hose, at least as long as the maximum length of the sludge suction hoses carried, should be mounted on a reel with winding arrangement.

e) INLET AND DISCHARGE VALVE

The inlet should be a lever-operated 100 mm globe or slide valve connected to an internal delivery pipe discharging against a wearing plate. The inlet should be angled downwards approximately 30° to the horizontal to follow the natural curvature of the hose.
The discharge valve should be 50 % larger than the inlet valve and should also be a globe or slide valve.

f) HOSES

Hoses should be of 100 mm diameter and of various length according to site conditions (for example some 10 m pieces and some 3 m pieces). The overall length should be some 60 m divided into 40 m of flexible hoses and 20 m of rigid pipe.

Suitable materials are:
(i) heavy duty PVC hoses for conventional vacuum tankers and steel-reinforced rubber (neoprene-lined) hoses for high capacity suction tankers;

(ii) rigid lightweight steel pipe (3 m long)

g) HOSE-COUPLINGS

To reduce hose blockages, it is very important to have couplings with a smooth bore and, if possible, no reduction in pipe diameter. Quick-release ball-clip or bayonet couplings may be suitable, but require a special hose-stretching tool for fitting them.

h) NOZZLES

High capacity suction tankers should be provided with a 2 m aluminium nozzle of 100 mm diameter, with an air bleed pipe to link the inlet end to the atmosphere. For deeper pits with difficult access, a 3 m long flexible hose with a short nozzle should also be available.

i) VACUUM BREAKER

For work with long pipes, there should be a facility to attach a vacuum breaker to one of the last pipe sections at the pit, to facilitate clearing of the nozzle inlet.

k) CREW ACCOMMODATION

Seats for the driver and 2 operators should be available in the cab and additional seating for 2 operators on a rear platform with railings would be appreciated.

l) HOPPER

A hopper to carry away the rubbish accumulated during emptying work should be provided on the tanker.

10.2 Draft Specification for Remote ('Mother and Baby') System

During the workshop in Gaborone, various 'mother and baby' systems were discussed. In general, two possible solutions were proposed:

- A sophisticated 'mother' unit (fully equipped suction tanker with pick-up platform for transporting the 'baby' unit) feeding a simple 'baby' (remote) unit through a long 75 mm air hose.
- A fully equipped 'baby' unit working independently and returning to a collection point when its tank is full, to be emptied by a vacuum tanker.

Both options deserve further investigation. However, the workshop felt that it was now the responsibility of the manufacturers to develop an appropriate design. To provide guidelines, specifications for the 'baby' unit were drafted. These are, however, only very preliminary indications and await further developments:

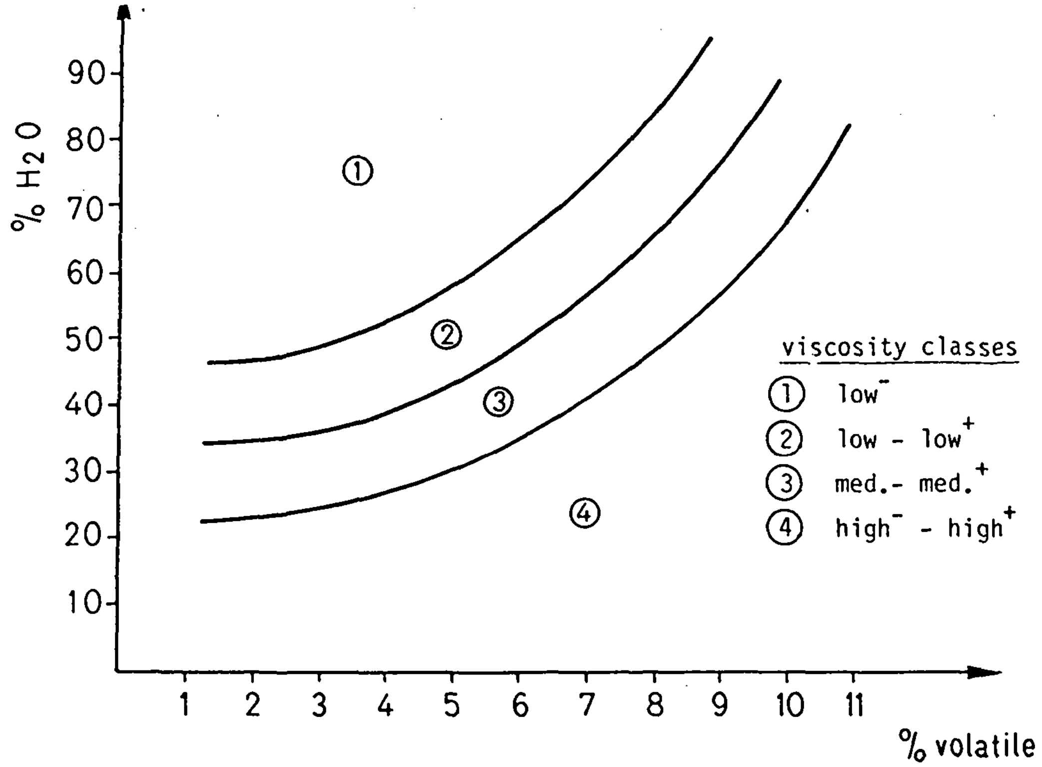
- maximum overall width 1 m
- maximum overall length 2 m
- maximum height 2 m
- holding tank capacity 1 m^3
- self-propelled (low power, high torque)
  capable of traversing rough or swampy terrain,
  gradients of up to 1 : 4 and steps
- wheels should be at least 600 mm in diameter
- ability to carry up to 20 m by 100 mm suction hoses.

11. CONCLUSIONS

11.1 Sludge Flow Behaviour

The flow behaviour and hence the 'pumpability' of sludge found in pit latrines can be determined by analysing its composition in terms of water and volatile content. Figure 11.1 classifies the flow behaviour into four viscosity classes according to the composition of a sludge.

Figure 11.1 Sludge Composition - Flow Behaviour

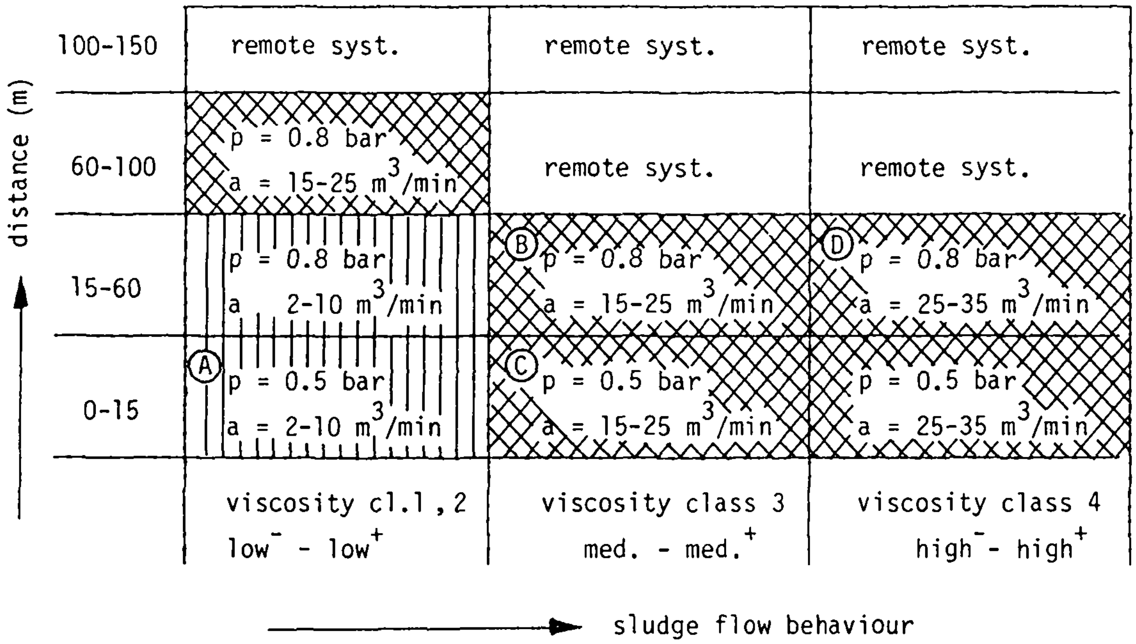


Another factor which has to be taken into consideration when pumping sludge is its density. There is no correlation between flow behaviour and density. A sludge of a medium viscosity for example can represent a density range of 1'051 up to 1'628 kg/m^3 (see page 30).

11.2 Technical Requirements for Sludge Removal

The characteristics of the sludge to be removed will influence the type of suction system chosen. Economic and maintenance considerations clearly dictate that the cheapest and simplest machine capable of doing the job should be used. The performance requirements needed for removing different types of sludge are given in Table 11.1, page 67.

Table 11.1 Matrix for Suction Equipment (pump) Selection



distance (m)			
100-150	remote syst.	remote syst.	remote syst.
60-100	▩ p = 0.8 bar a = 15-25 m^3/min	remote syst.	remote syst.
15-60	▥ p = 0.8 bar a 2-10 m^3/min	▩ Ⓑ p = 0.8 bar a = 15-25 m^3/min	▩ Ⓓ p = 0.8 bar a = 25-35 m^3/min
0-15	▥ Ⓐ p = 0.5 bar a = 2-10 m^3/min	▩ Ⓒ p = 0.5 bar a = 15-25 m^3/min	▩ p = 0.5 bar a = 25-35 m^3/min
	viscosity cl.1 , 2 low^- - low^+	viscosity class 3 med. - $med.^+$	viscosity class 4 $high^-$ - $high^+$

p = rel. vacuum (bar)
a = airflow (m^3/min)

▥ vacuum system
▩ pneumatic conveying system (air bleed nozzle or plug drag method)

Ⓐ POOLE Tanker
Ⓑ ROLBA Tanker
Ⓒ ALH Equipment
Ⓓ BREVAC Tanker

This Table is valid for level sites only, 100 mm diameter hoses and a max. pit depth of 3 m.

- thin sludges with a viscosity up to the low$^+$ range can easily be pumped with a vacuum system. The required pump performance would need to be 0.5 bar suction and have a maximum airflow between 2-10 m^3/min. for shifting the sludge along a 15 m by 100 mm hose and 0.8 bar, and 2-10 m^3/min for shifting the sludge along a 60 m pipe.

- To transport medium and high-viscosity sludge along a pipe, the application of a pneumatic conveying system is required. There are, however, different methods of achieving pneumatic conveying, i.e. constant air drag system (open nozzle a few centimeters above the surface of the sludge), air bleed nozzle and the plug drag ('suck and gulp') method. For medium and high-viscosity sludge, the use of an air bleed nozzle or the plug drag system is appropriate and both have proved to be very efficient in removing these types of sludges. The appropriate pump would need a performance of around 0.5 bar suction and a maximum airflow between 15-25 m^3/min. to shift the sludge along a 15 m by 100 mm hose and 0.8 bar, and 15-25 m^3/min. to shift the sludge along a 60 m pipe. For distances beyond 60 m, a remote system should be considered.

- To transport very compact sandy material, a higher airflow rate is essential to work with a combination of constant air drag system and plug drag method. The pump performance required is about:
  - 0.5 bar suction and a maximum airflow between 25-35 m^3/min. for 15 m by 100 mm pipe
    and
  - 0.8 bar and a maximum airflow between 25-35 m^3/min. for a 60 m long pipe.

  Distances beyond the 60 m value should be covered with a remote system.

- If the material is too dry to allow immersing of the nozzle end into the material, the application of the constant air drag system will be necessary. This method, however, calls for large centrifugal fans which can displace a lot of air, up to 100 m^3/min. and more. In general, such machines are expensive, usually very sophisticated and therefore not appropriate for use in developing countries. In addition to this, the friction loss in the pipe is high due to the high air velocity. The mode of handling the hose requires great operating skill to keep the hose inlet a few centimeters above the surface of the sludge. As far as single-pit latrines are concerned, access to the pit contents is only through the small squat-hole, thereby making this emptying method impossible.

Although it proved possible to pump thin sludge through a 100 m by 100 mm pipe, distances beyond this 100 m value should not be considered mainly because of the following facts:

- very long times are required for setting-up, dismantling and washing-down (the setting-up time for a 70 m pipe was found to be 15 min. and 20 min. for dismantling and washing-down);

- if a blockage occurs, it is very difficult and time-consuming to locate the position of the obstacle in such a long pipe with many joints;

- communication between the hose operator and the worker operating the suction valve on the tank over a 100 m distance is very difficult as they may be out of earshot and unable to see each other.

- the accumulation of mud layers in the pipes and hoses which had to be rinsed out periodically by sucking water through the pipe.

11.3 Access to the Latrines and their Contents

Another important factor governing the technical limits of mechanical systems for emptying pit latrines is the accessibility which is determined by two aspects:

a) the distance between the pit and the place where a suction tanker can get the closest. This distance depends on the environment and differs very much from place to place. In Gaborone, access to the latrines was very good, in most cases within 15 m, while conditions encountered in Dar es Salaam were a lot more difficult and distances of up to 100 m were measured.
It can be concluded from the tests that when shifting heavy sludge, the pipe should not be longer than 60 m. Distances beyond 60 m should be served by a remote system where only air is moved through the long pipe;

b) the size of the widest available opening to reach the pit contents. This depends on the latrine type. For all unimproved and single-pit VIP latrines, emptying is carried out through the squat-hole. Handling of the hose in these circumstances is very tiresome, and work with a nozzle is limited to two meters since the joint on its upper end will not go through the hole. It is therefore of utmost importance that all new latrines are equipped with removable slabs providing easy access to the pits.

It is most important that the overall size of the equipment is taken into consideration when selecting machinery to work in a particular environment. For instance, in areas with poor access such as Dar es Salaam, small tankers will probably be appropriate, but in Gaborone where access is good, larger machines may be used.

11.4 Types of Equipment Tested and their Limits

The tests in Gaborone have shown that the ROLBA, BREVAC and ALH prototypes are capable of removing the high-viscosity sludges which are often found in pit latrines. The high airflow rate of BREVAC made it possible to shift even dry sandy soil along a pipe.
The practical and technical limit for the maximum distance between the tanker and the latrine when shifting high-viscosity sludge along a pipe was found to be approximately 60 m. The limiting factor is the reduction in suction power due to the high friction loss caused by a build-up of mud layers inside the pipes. In areas where tankers cannot get closer than 60 m to the latrines, and where medium or high-viscosity sludge has to be handled, an alternative system with a remote unit has to be used. Guidelines for the specification of such a remote unit are given in section 10.2, page 64.

The specification proposal regarding suction tankers is given in section 10.1, page 62.

The limits of performance of all the equipment tested are summarized in Table 11.2, page 71.

Table 11.2: Performance Limits of the Equipment Tested

	Sludge limit for a 1.5 m deep pit	Sludge limit for a 3 m deep pit	Limit of suction distance	Pits served per day (average)
CALABRESE	low$^-$	low$^-$	(36 m)	10 - 15 liquid layer only
POOLE	low$^+$	low	20 m	12 - 17 liquid layer only
ROLBA	high	med$^+$	58 m	8 - 14
BREVAC	high$^+$	high$^+$	64 m	10 - 15
ALH	high$^+$	?	ALH 60 m. For remote systems in general up to 150m	?
BUMI PUMP	low$^-$/water	low$^-$/water	-	-

11.5 Maintenance

Unfortunately, none of the prototypes were tested in Gaborone for more than four months. Therefore, it is difficult to assess their long-term maintenance and reliability. However, one tanker, BREVAC, is still in Gaborone undergoing supervised trials for an additional one year period as part of BRE's agreement with the Government of Botswana. According to the latest information, BREVAC's suction unit is still working well (after one year), but some problems in getting spare parts for the Ford Chassis were reported from Gaborone.

12. SUGGESTION FOR FURTHER WORK

With the field tests described in this report, the technical limits of the different equipment used in handling different types of sludges could be established. However, some questions in connection with the construction and operation of pit emptying systems and technologies suitable for developing countries still remain unanswered and require further investigations:

- The development of an alternative system is necessary for areas where tankers cannot get closer than 60 m to the pits, and where medium or high-viscosity sludge has to be handled. Under these circumstances, the development of a system with a remote unit is suggested. Based on our present knowledge about typical location of and accessibility to latrines in urban areas of developing countries, a draft specification for such a remote system is given in this report (see section 10.2, page 64). However, it would be higly desirable to know more about the various conditions encountered in the developing world. This could be achieved by conducting a systematic survey of different towns in different continents.

- The tests in Gaborone which lasted 4-5 months could not answer the crucial question of how well the equipment operates over a long-term period under difficult conditions. Therefore, the BREVAC tanker, the ROLBA tanker and the remote system to be developed, should be tested for at least one year under real-life conditions as encountered for instance in many African cities. Dar es Salaam (Tanzania) would be a good place to observe the long-term performance under such difficult conditions.

- In order to optimize the construction and operation of emptying equipment, it would be highly desirable to conduct further laboratory tests to establish the influence of air velocity on the flow rate for low, medium and high-viscosity sludge.

13. CONSEQUENCES FOR PLANNING AND DESIGN OF SANITATION SYSTEMS

The tests in Gabarone have shown that any equipment capable of handling heavy sludge is not simple, nor easy to operate and maintain. On the other hand, equipment which is considerably cheaper and relatively easy to operate and maintain can handle only water and thin sludges. This fact should influence the planning and design of future sanitation systems, especially in areas of developing countries where sophisticated machines cannot be maintained and operated properly over a long period.

Appropriate planning of latrine location as well as design of the single pits can facilitate considerably the emptying procedure and therefore lower the requirements of the emptying equipment. When planning a sanitation system, it should be taken into account that a medium sized tanker is to get as close to the latrine as possible. Easy access to the pit itself in the form of removable covers is also most important.

Under existing conditions, planners have a choice between two systems: the vault latrines, with a relatively small tank easily emptied by a simple vacuum truck, but requiring a reliable emptying service and producing a greater amount of sludge to be handled and discharged to the environment; or the pit latrines, which can accept considerable quantities of water and are less liable to overflow in the absence of reliable pit emptying services, but accumulate compacted sludge which can only be removed by sophisticated equipment.

Properly operated twin-pit latrine systems retain all the advantages of pit latrines, whilst allowing for simple manual removal of pit contents without health hazards. These systems take maximum advantage of locally available resources: subsoil for liquids removal by soakage and manpower for solids removal. Thus, in addition to providing a high level of service, another equally important objective, non-reliance on imported technology, is achieved. Where physical and socio-cultural conditions permit, this is definitely the best choice of technology.

Impermeable substrata such as clay or rock, however, preclude the use of pit latrines. In these cases, any latrine built will essentially be a vault where all the liquids and solids are retained for collection. Earlier studies by IRCWD 5/ on compaction of sludge indicate that the content of the vault can be removed by regular vacuum tankers if the sludge is stored for not more than one year.

However, it has to be kept in mind, that many urban areas have already established traditions of latrine construction and use, and that the sludge will have to be removed from thousands of latrines which have not been planned and designed in an optimal way to allow easy emptying. Any pit emptying service must clearly adapt itself to the requirements of the particular latrine technology already in use. Under such prevailing conditions, probably the most appropriate economic and operational solution would be to set up a tanker fleet with simple vacuum tankers which are relatively easy to operate and maintain, and some units of a more sophisticated type. The latter which are far more expensive and more difficult to operate and maintain, will have to be used only for emptying pits of difficult access and containing heavy sludge.

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1. ABSTRACT ON PNEUMATIC CONVEYING SYSTEMS

In pneumatic conveying systems, solids are transported by being suspended in a high velocity stream of air. Very little is known, however, about the influence and the upper and lower limits of conveying air velocity. Typical minimum air velocities are of the order of 13 to 17 m/s for horizontal conveying. The appropriate air velocity, however, depends very much upon the type of product being conveyed, i.e. for a regularly-shaped corn with a density of about 500 kg/m^3, the appropriate air velocity is around 18 m/s, for an irregularly-shaped corn with a density of about 800 kg/m^3, it is between 25 and 30 m/s and for sludge with a density of more than 1000 kg/m^3 35 m/s. In addition to the material transported, the pipeline will also affect the optimum air velocity and so, each case must be considered individually 10/.

Figure I.1 illustrates how the material transported can affect the optimum air velocity and product flow rate.

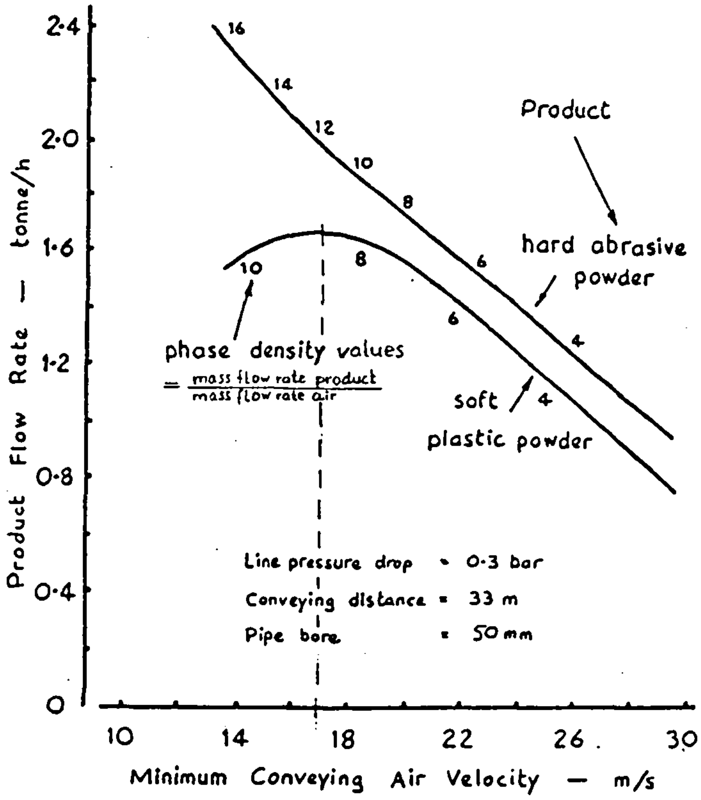


Figure I.1: Influence of Air Velocity and Product Type on Product Flow Rate (Laboratory of Thames Polytechnic)10/

In both cases (soft and hard powder) it can be seen that the product flow rate decreases considerably with an increase in velocity, hence the phase density, which is a dimensionless ratio between product mass flow rate and air mass flow rate, decreases as the air velocity increases. The lowest air velocity limit to convey both the soft and the hard powder, was found to be 13 m/s.
For the plastic powder, the optimum air velocity would be about 17 m/s, and for the abrasive powder 15 m/s, in order to obtain a reasonably high product flow rate and still keep sufficiently clear of the minimum conveying velocity of 13 m/s.

In order to identify the optimum air velocity for transporting sludge, it would be necessary to repeat these experiments using different sludge types (for example low, medium and high-viscosity sludge). Having established the range of optimum velocity the performance characteristics of the vacuum equipment needed for the transport of sludge could be defined. It should be emphasized that air velocities higher than the optimum should be avoided because less sludge can be transported and the increased friction losses in the pipes would waste energy.

The results of the field tests in Gaborone seem to indicate that the appropriate air velocity for transporting high-viscosity sludge is about 36 m/s (ROLBA max. air velocity for 100 mm hose) and 55 m/s for compact sandy material (BREVAC max. air velocity for 100 mm hose).

1. THEORETICAL FOUNDATION

1.1 Possible Measuring Terms for Sludges

In order to determine the performance limits of suction systems, it is necessary to measure a characteristic parameter representing the flow behaviour of the sludges removed. Such a representative term cannot be found easily since the sludges in question vary widely in character and their flow behaviour is difficult to define.

It would be useful to determine the viscosity η of a sludge, but unfortunately it is not constant and varies with changing shear rate γ (Figure II.3) and is thus a non-Newtonian liquid. One should therefore not refer to viscosity but to apparent viscosity. An alternative to the direct measurement of viscosity would be to consider the sludge composition, particularly solids concentration and particle size distribution. These two approaches to the problem are discussed in sections 1.2 and 1.3 of this Appendix.

1.2 Theoretical Consideration of the Rheology of Sludges

Sludges are a very complex mixture of organic and inorganic components. It is therefore necessary to use a simple approximation of their composition when considering the theoretical analysis of their behaviour. A suitable model is a suspension of solid particles in a liquid.

The rheological properties of suspension are basically dependent on temperature, pressure and on the volumetric solids concentration. Pressure and temperature were assumed to be constant during measurements in Africa, so our theoretical analysis needs to consider the effect of solids concentration only.

Based on the assumption that the particles in the suspension are small compared with the measured flow, and the inertia negligible, A. Einstein calculated the relative viscosity η/η_0 as a function of the volumetric solids concentration ϕ for diluted suspensions /11/:

$$\eta/\eta_0 = 1 + 2,5 \cdot \phi$$

where η_0 is the viscosity of the pure suspension liquid.

To characterize the viscosity of highly concentrated suspensions, Frankel and Acrivos have established an equation which neglects all inertia and wall effects 12/:

$$\eta/\eta_0 = B \frac{(\phi/\phi \text{ max.})^{1/3}}{1 - (\phi/\phi \text{ max.})^{1/3}}$$

where B = relative sediment volume of the suspension

$$B = \frac{V \text{ sediment}}{V \text{ solid}} \quad \text{and}$$

Ø max. = max. volumetric solids concentration.
The space between two particles thus becomes negligibly small.

These two equations are shown in Figure II.1.

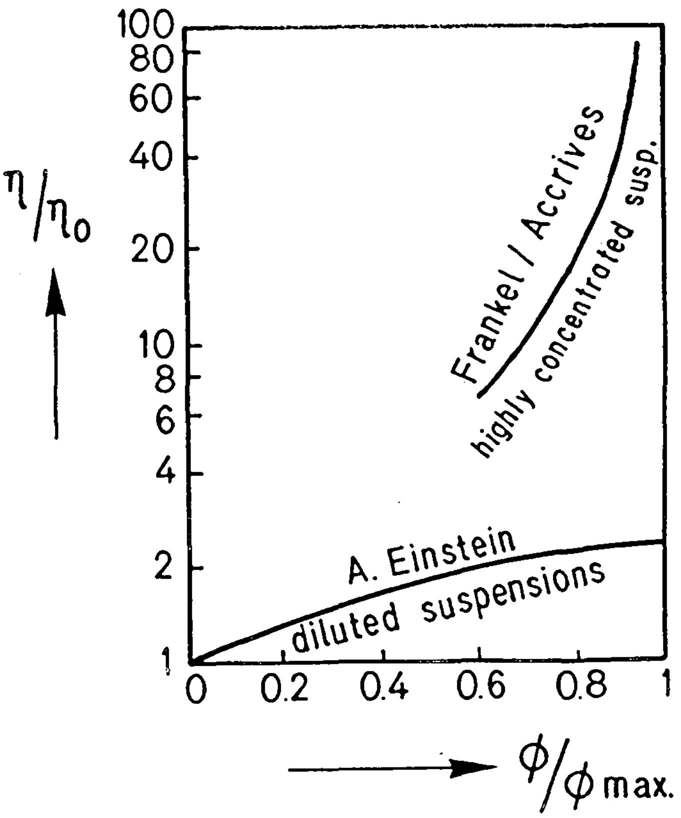


Figure II.1

Apart the Einstein and Frankel/Acrivos' equations, several other authors have tried to establish relationships between these two limiting values in suspensions. The question of which of these equations is finally the most appropriate for representing a given sludge is dependent on:

- the type of suspension agent
- the type of solid or solids
- particle shape
- particle size
- particle size distribution

Because particle size, particle shape and particle size distribution affect the viscosity of the suspension to a significant degree and because these parameters are very difficult to measure, particularly under Third World conditions, it was concluded that this was an impractical approach.

1.3 Direct Measurement of Viscosity

Several rheological models have been developed to characterize the flow behaviour of liquid and sludges see Figure II.2. Basically, they can be divided into two groups:

- some with yield stress τ_0 and
- some without yield stress

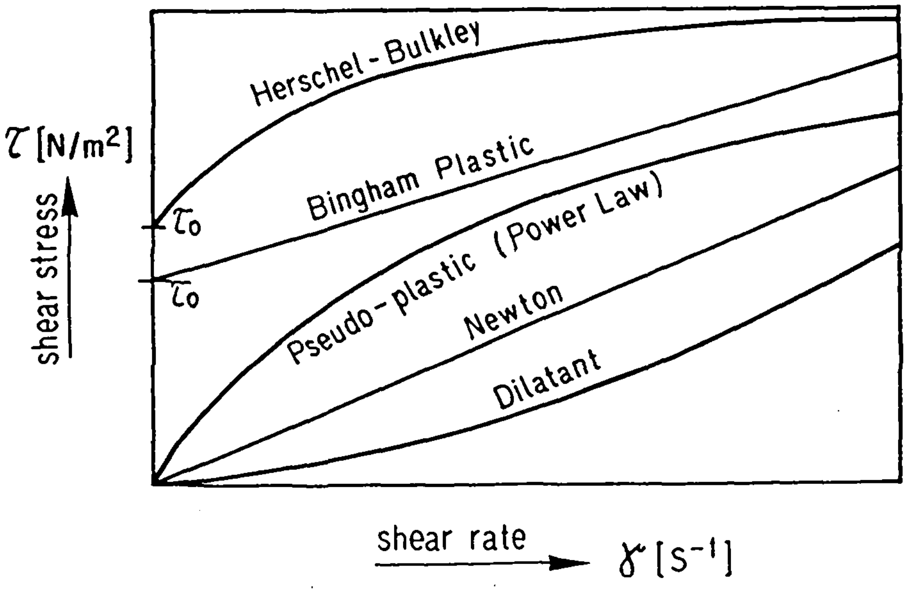


Figure II.2

In his studies carried out in Dar es Salaam and Gaborone, Peter Hawkins tried to adapt the measured data to a pseudo-plastic (Power Law) model which, however, ignores the existence of a yield stress τ_0 2/. The British Hydromechanics Research Association (BHRA) which was commissioned by BRE to study the simulation of sludge, first used the Herschel-Bulkley Model 9/. However, it soon had to discard it since the theoretically calculated yield stress τ_0 differed completely from the measured value. Even the attempt to first subtract the measured τ_0 from the shear stress τ and then to adapt it to the pseudo-plastic model failed, because in over 25 % of the samples the τ_0 was greater than τ (Figure II.3).

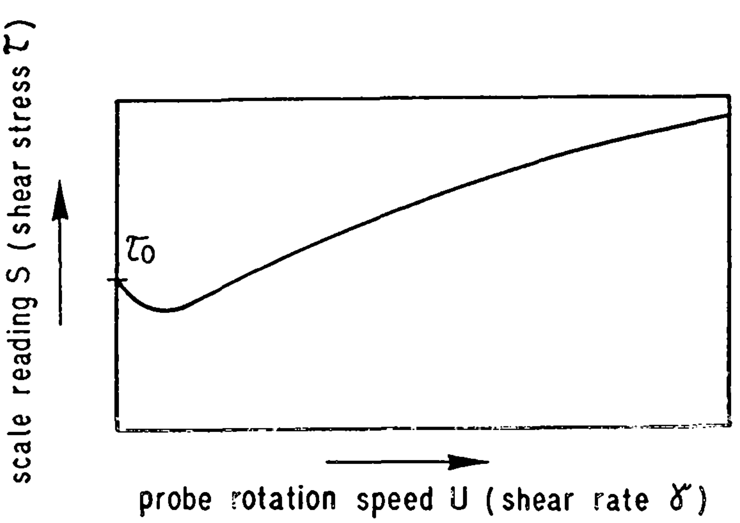


Figure II.3

Finally it was decided to use the pseudo-plastic model directly, using only the first six readings for each sample tested by Hawkins, to determine the flow parameters N and K.

According to Haake, the conversion factor A with which the scale reading S shown on the viscometer can be converted to τ_0 and τ is 3.88 (Pa/scale grad). This value was also used by Hawkins. The BHRA, however, was not satisfied with this value and used its own calculated value of 4.81 (Pa/scale grad).

Because of these problems and disparate views, and due to the fact that the measurements with the rotary viscometer are subject to great variation, it was finally decided not to carry out any theoretical calculations related to the flow behaviour of sludges. Instead of comparing converted values N, K, τ and τ_0, the plotted flow curves were compared directly with each other. To do this, the whole measuring range has been subdivided into a low$^-$, low, low$^+$, medium, medium$^+$, high$^-$, high, high$^+$ ranges (see Figure 5.2 page 32).

However, to obtain representative measurements, which can be reproduced, it is absolutely necessary to adhere to a strictly defined 'measuring ritual'. The standard laboratory procedure (see Appendix III) was dictated by considerations of the thixotropic nature of the sludge.

1.3.1 Thixotropy

Certain fluids are known to possess a 'power of recollection' of their past hydrodynamic history. This manifests itself in a time-dependent behaviour, i.e. at constant shear rate γ, the value of shear stress τ during a long period of strain, varies according to the preceding strain to which it has been subjected. Depending on the fluid used, shear stress τ may increase or decrease.

A fluid which exhibits a decrease in viscosity at constant shear rate, and regains its original value after the removal of the strain, is known as thixotropic.

Eduard Luggen distinguishes between the following types of shear rate/shear stress curves (Figure II.4) 13/:

a) TE (Thixotropic Equilibrium) curve;
b) DTS (completely Destroyed Thixotropic Structure) curve;
c) RTS (entirely Rebuilt Thixotropic Structure) curve.

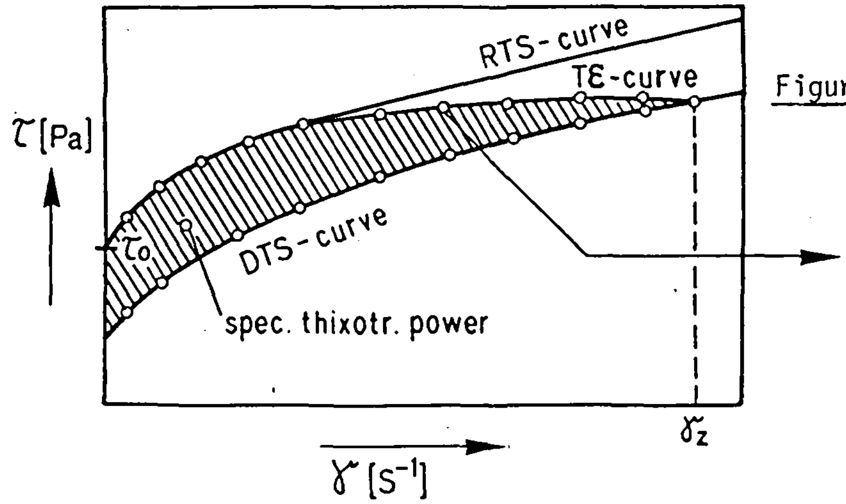
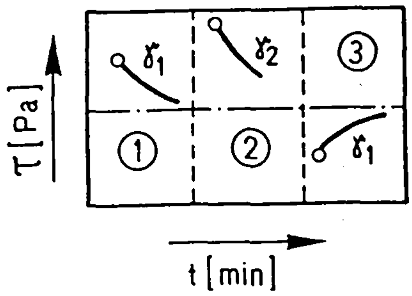


Figure II.4

Figure II.5



a) TE curve (Thixotropic Equilibrium)

A thixotropic fluid develops a three-dimensional structure by polimerization of individual particles. This is then called a thixotropic structure. These structures are broken down by shearing but are readily rebuilt as soon as the strain ceases. Thixotropic equilibrium is reached if the shear stress applied breaks down an equal amount of thixotropic structure as the sludge is rebuilding. In practice this TE curve is reached in stages: A predetermined shear rate γ_1 is applied until the strongest variation of shear stress τ has subsided as it approaches the value for τTE (curve 1 in Figure II.5); it is then sheared for a short time with a higher shear rate γ_2, to speed up destruction of thixotropic structures (curve 2 in Figure II.5); the shear rate γ_1 is reapplied and the shear stress will gradually increase as it approaches the equilibrium value τTE asymptotically (curve 3 in Figure II.5). The value for τTE is taken as the average between the final points on curves 1 and 3. This procedure is applied to each point measured. As each value for shear stress obtained by this method is for an equilibrium condition, the results are independent of the time taken to measure them and the curve can be fully reproduced.

This procedure can be used successfully with many thixotropic substances. With sewage sludges, however, the thixotropic structure which has been broken down redevelops only very slowly, and because the equilibrium value is approached asymptotically, the time needed to produce reliable results would be unreasonably long.

Luggen discovered that with sewage sludges, the TE curve can be approached if the shear rate γ is continuously increased with a constant acceleration. Unfortunately, the probe speed of the available viscometer (Haake VT 181) is not infinitely adjustable and can only be set at six different speeds by a frequency transformer. The 'speed-shocks' caused by increasing the speed in steps, tend to break down the thixotropic structure and will therefore influence the results.

Several laboratory experiments at EAWAG in Dübendorf have nevertheless shown quite good results, particularly in the lower measuring range, where the shear rate γ is slow and the increase in shear rate between steps is small. In the upper range, however, the curve levels off rapidly since the thixotropic structure is broken down by the speed changes, which results in the measured values for shear stress being lower than the TE curve.

Experiments at the Haake laboratory in Horgen, Switzerland, in which a Rotovisco RV 100 computer-controlled viscometer (constant acceleration of the speeds of rotation) was compared with our VT 181, have shown that the TE curve plotted with the VT 181 differs greatly from the curve plotted by the Rotovisco. The DTS curve, however, was the same for both measuring instruments. This is a clear indication that the DTS curve should be considered in more detail as it seems to show a reproducible and time-independent behaviour.

b) DTS curve (completely Destroyed Thixotropic Structure)

The DTS curve represents the behaviour of the medium with a thixotropic structure which has been completely broken down. No shear rate γ will allow the medium to rebuild thixotropic structure. This is reached by first applying a shear rate greater than γ_Z, the shear rate which breaks down all thixotropic structures. At this point, the DTS curve meets the TE curve (see Figure II.4.). This shear rate is applied until the shear stress τ becomes invariable. Then, a lower shear rate is applied and the scale read immediately before a new structure is built. This procedure is repeated for different shear rates to gradually plot a DTS curve. With this special measuring procedure, the influence of time is eliminated and so the curve can be reproduced.

Such high shear rates as γ_Z cannot be achieved with the VT 181 viscometer. Since sludge possesses rather sluggish properties, the same effect can nevertheless be achieved by setting the highest shear rate (button 1) until the shear stress τ becomes invariable, and then resetting to a lower shear rate and reading the scale immediately. This measuring procedure has to be repeated for every point measured.

c) RTS curve (entirely Rebuilt Thixotropic Structure)

With an RTS curve it is assumed that the thixotropic structure is preserved at all shear rates. In practice, however, this is very difficult to achieve and it is therefore of no practical importance.

1.3.2 Significance of the TE and DTS curves

The rheological character of the material can be determined from the position of the curves in the τ-γ diagram. Should the TE curve coincide with the DTS curve for all shear rates, then we are dealing with one of the substances illustrated in Figure II.2. Should the TE curve lie above the DTS curve, then we are dealing with a thixotropic substance or with a rheopectic substance if the TE curve falls below the DTS curve.

1.3.3 Significance of laboratory procedures

Peter Hawkins 2/ and BHRA 9/ used the same experimental procedure. First, the yield stress τ_0 was determined by turning the sample container very slowly until the probe started to slip relative to the sludge. Then, the curve was plotted by starting at the highest shear rate (button marked 1), descending gradually to zero and back again. Since this method neither corresponds to a TE nor to a DTS curve determination, and since the measuring system is dependent on time, the results obtained will be subject to great variations.

Clearly, if this sort of problem is to be avoided, a standard laboratory procedure must be established and adhered to rigidly.

The procedure which is derived from these considerations of viscosity measurement is given in Appendix III.

1. LABORATORY PROCEDURES

1.1 Viscosity Measurement

The measurement procedure described here produces a result equivalent to a DTS curve (thixotropic structure which has been completely broken down, see Appendix II), which is reproducible and can be used to compare excreta- derived sludges.

These instructions apply to the Haake VT 181 viscometer with frequency transformer and E 100 cylindrical sample probe.

1. Determine the static yield stress τ_0 by turning the sample container slowly until the probe begins to slip relative to the sludge.

2. Increase the shear rate γ as fast as possible, starting at the minimum speed (button marked 32) until an approximate TE curve is obtained (subject to great variation).

3. Keep the probe running at top speed (button marked 1) for at least 1 min. until the shear rate τ has dropped slightly and becomes stable.

4. Reduce one speed step (button marked 2) and take the scale reading S at once. Increase the speed again back to maximum shear rate (button marked 1) to break down all thixotropic structures again.

5. After a few seconds the next speed (button marked 4) should be engaged and the scale reading taken immediately before turning the instrument back to maximum speed.
   Repeat this procedure for all speed settings.

1.2 Analysis of Sludge Composition

Sludge analysis in terms of water content, volatile and non-volatile content is carried out as follows:

1. After the viscometer test, the sludge is mixed thoroughly and a sample of 25-30 g is weighed in an appropriate crucible. To determine the water content, the sample is dried for 24 h in a furnace at 105° C.
2. Cool the dried sample in a desiccator and reweigh to calculate the water content.
3. Break up the sludge cake in the crucible and heat for 1 hour in a furnace at 550° C.
4. Cool the sample in a desiccator and reweigh to calculate the volatile and non-volatile content.

The weight fractions are calculated as follows:

Weight fraction water: $$Ww = \frac{Mwc - Mdc}{Mwc - Mc} \circ 100\ \%$$

Weight fraction volatile: $$Ww = \frac{Mdc - Mic}{Mwc - Mc} \circ 100\ \%$$

Weight fraction non-volatile: $$Wnv = 100\ \% - Ww - Wv$$

where:
Mwc = weight of wet sample and crucible (g)
Mdc = weight of dried sample and crucible (g)
Mic = weight of incinerated sample and crucible (g)
Mc = weight of crucible (g)
Ww = weight fraction water (%)
Wv = weight fraction volatile (%)
Wnv = weight fraction non-volatile (%)

All weight fractions are based on the original wet weight (100 %).

1.3 Density Measurement

Weigh the mixed sludge in a 250 ml measuring flask. Density ρ is calculated as follows:

$$\rho = \frac{Msm - Mm}{250} \cdot 1000 \left[kg/dm^3\right]$$

where:
Msm = weight of sludge with measuring flask (g)
Mm = weight of measuring flask (g)
250 : weight of 250 ml water (g)

1. COMPARISON OF VACUUM PUMPS USED

In general, three different vacuum pumps can be used for evacuating slurry tanks; these are:

1.1 Sliding Vane Vacuum Pump

The sliding vane pump is a relatively compact, well-proven, cheap pump which consists of a rotator with sliding vanes (blades) mounted eccentrically in a housing. As the rotor turns, the centrifugal power forces the blades against the case wall and, since the rotator is located eccentrically to the casing, the blades slide in the rotator's gap. The pumps themselves are relatively simple to maintain but require regular checking and a steady supply of spares. In addition, this type of pump is very susceptible to blockage and damage by soil and sludge particles and therefore, requires a very good sludge and water separating system. As its capacity is lower than that of a similar-sized liquid ring pump, larger pumps which need an additional cooling system have to be used.

1.2 Liquid Ring Vacuum Pump

This type of pump consists of a rotating impeller which is mounted eccentrically in a casing of circular cross-section, with a service liquid acting as a seal between the casing and the impeller (see Appendix V, page 5). This has some advantages over the sliding vane type of vacuum pump:

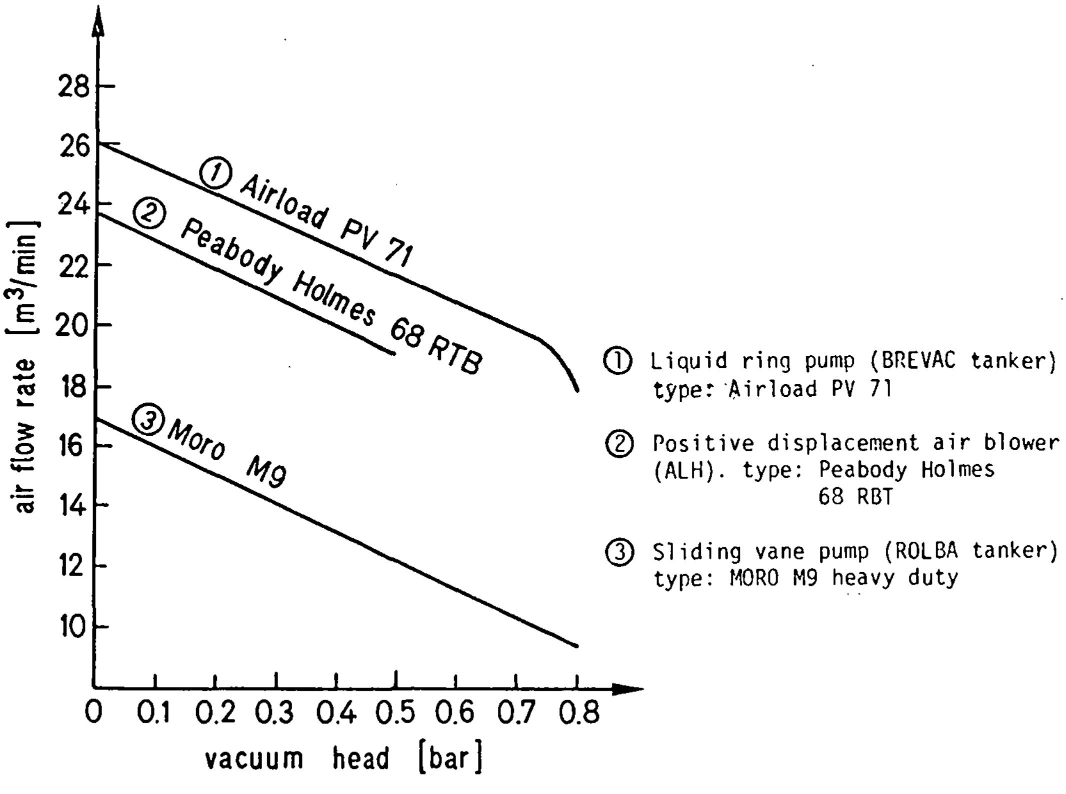
- fewer moving parts as there are no sliding vanes and hence, little mechanical wear;
- capable of handling entrained liquid and sludge, as the service liquid (water) helps to remove them;
- self-cooling, as the service liquid also acts as a coolant.

The pump, however, requires extra pipework, a service liquid separator and service liquid tank which increases its cost relative to the sliding vane pump. Although there is not much field experience with liquid ring pumps in Third World countries, this system is expected to turn out to be more reliable in the long-term, despite its extra pipework for the service liquid.

1.3 Positive Displacement Rootes Blower

This type of vacuum pump displaces a large volume of air, but creates only a moderate vacuum head and is therefore suitable for applications where higher flow rates are required. It consists of two bone-shaped impellers rotating in a cogwheel motion and thereby producing a vacuum between the impellers and the case. To keep the pump in continuously good performance, a very good sludge and water separator or even an air filter should precede the intake of the pump. In addition, they run at high speed, producing a lot of noise which has to be reduced by means of a silencer.

Figure IV.1 Performance Comparison of the Vacuum Pump Used



Liquid ring vacuum pumps clearly have many advantages over sliding vane and positive displacement pumps, but these have to be offset against the extra cost of the service fluid circuit. It must be stressed, however, that heavy duty sliding vane pumps require an additional cooling system and very good sludge separating systems which increases the cost to almost that of a similar-sized liquid ring pump. It would therefore make sense to equip conventional vacuum systems with cheaper low-volume sliding vane pumps, and use liquid ring pumps when high suction performance is essential.

Reavell APPENDIX V/1 **CompAir**

series 100 compressors and exhausters

Compact simplicity, versatility, high efficiency and reliability. These are the basic reasons why Reavell rotary compressors and exhausters are designed into the products of leading machinery makers—why they perform an essential part in so many industrial processes.

These smooth-running Reavell units require very little in the way of space and ancillary equipment--giving maximum freedom of installation on both technical and economic grounds.

Series 100 compressors and exhausters are available in either lubricated or oil-free versions, as basic machines or complete self-contained package units with electric motor and baseplate. And, like all Reavell products, they are made to last.

Design features include:

COMPACT DESIGN – gives easy installation.

VIBRATION FREE – no receivers or foundations required.

SIMPLE CONSTRUCTION – no valves, therefore low maintenance costs.

LONG-ESTABLISHED – proven reliability for wide variety of applications.

performance data

COMPRESSOR

FREE AIR DELIVERED

MODEL	SPEED rev/min	METRIC				IMPERIAL			
		0·7 bar		1·4 bar		10 lbf/in²		20 lbf/in²	
		m³/h	kW	m³/h	kW	ft³/min	hp	ft³/min	hp
OIL LUBRICATED									
R107*	900 1450	52·7 87·5	1·5 2·7	47·6 81·6	2·7 4·0	31·0 51·5	2·0 3·65	28·0 48·0	3·5 5·4
R108*	900 1450	76·5 139·2	2·1 3·7	63·0 122·4	3·7 5·7	45·0 82·0	2·8 5·0	37·0 72·0	5·0 7·6
R110P†	900 1450	109·5 186·9	3·4 7·4	98·6 174·2	5·2 9·5	64·5 110·0	4·6 9·9	58·0 102·5	7·0 12·7
OIL FREE									
R107NF*	600 1450	26·6 90·0	1·15 3·10	81·6	4·22	15·5 53·0	1·61 4·14	— 48·0	— 6·33
R108NF*	900 1450	76·5 138·6	3·78 5·92	68·0 [illegible]	4·55 6·61	45·0 81·6	5·06 7·94	40·0 76·6	6·10 8·86

EXHAUSTER

VOLUME ASPIRED

MODEL	SPEED rev/min	METRIC				IMPERIAL			
		254mm Hg		508mm Hg		10in Hg		20in Hg	
		m³/h	kW	m³/h	kW	ft³/min	hp	ft³/min	hp
OIL LUBRICATED									
R107*	900 1450	58·7 96·0	0·9 1·64	52·6 88·3	1·2 2·09	34·5 56·5	1·2 2·2	31·0 52·0	1·6 2·8
R108*	900 1450	81·0 139·3	1·3 2·3	59·4 118·8	1·6 2·9	48·0 82·0	1·7 3·1	36·0 70·0	2·1 3·9
R110P†	900 1450	118·1 187·2	2·2 4·2	98·6 [illegible]	2·5 [illegible]	69·5 110·0	3·0 6·55	58·0 99·5	3·3 6·9
OIL FREE									
R107NF	600 1450	34·0 94·4	0·69 2·40	82·1	2·83	20·0 55·0	0·92 3·22	-- 48·5	— 3·85
R108NF	900 1450	88·4 147·8	1·71 3·09	51·0 108·7	2·05 3·45	52·0 87·0	2·30 4·14	30·0 64·0	2·76 4·60

*Suitable for intermittent duty at pressures to 1·73 bar (25 lbf/in²) and vacua to 584mm Hg (23in Hg).

†Suitable for intermittent duty at pressures to 2·07 bar (30 lbf/in²) and vacua to 635mm Hg (25in Hg).

Publication 7010

general specification

Direction of rotation

Clockwise looking on driving end.
Anti-clockwise drive to order.

Cooling

Models—R107, R108, R110P: Air convection cooling.
R107NF, R108NF: Fan-cooled.

Lubrication

Models—R107 R108: Two automatic oil lubricators for internal working parts and ball bearings.
R110P: Pressure feed to all parts by mechanical pump.
R107NF, R108NF: Oil-free machines—no lubrication required.

Connections

Suction and delivery connections screwed Rp 1½.

Blades

Models—R107, R108, R110P: Heat stabilised resin bonded fabric—six in number.
R107NF, R108NF: Resin bonded carbon—six in number.

Bearings

Models—R107, R108, R110P: Ball bearings.
R107NF, R108NF: Ball bearings sealed for life and packed with high temperature silicone grease.

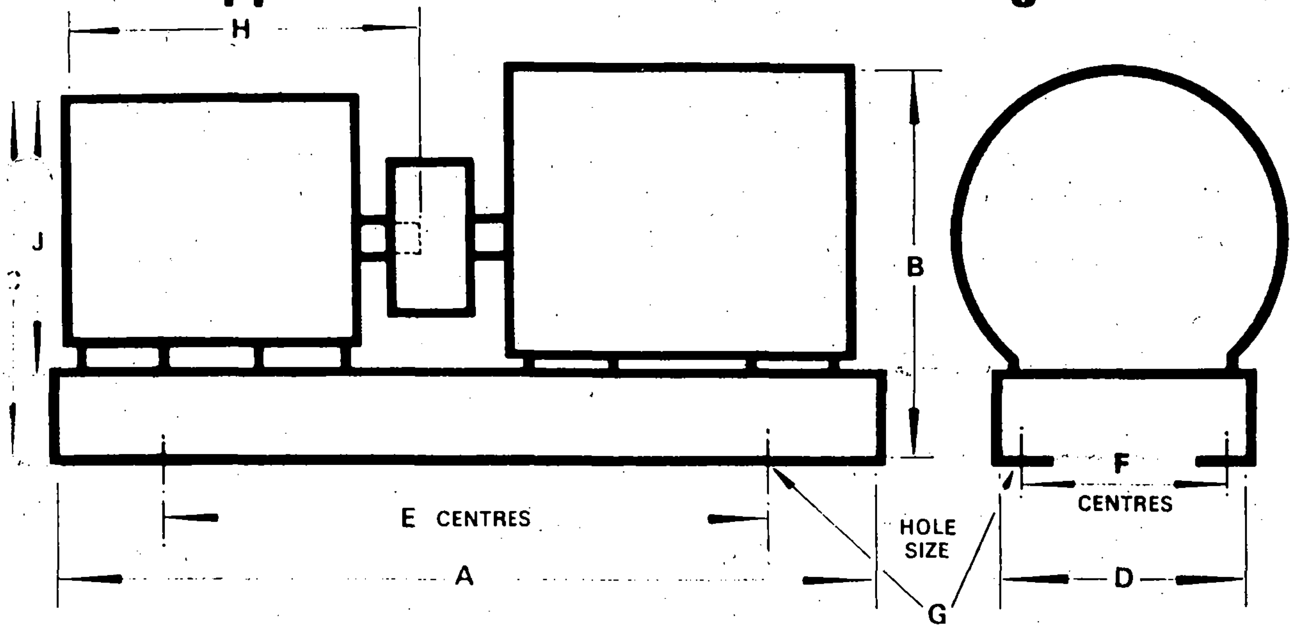
Shaft size

31·8mm (1¼in).

Drive

Electric motor, petrol or diesel engine, direct-coupled or via V-belt.
Details of bedplate-mounted units available on request.

approximate dimensions and weights



MODEL	MOTOR FRAME SIZE	METRIC										IMPERIAL									
		A mm	B mm	C mm	D mm	E mm	F mm	G mm	H* mm	J* mm	Weight kg	A in	B in	C in	D in	E in	F in	G in	H* in	J* in	Weight lb
7	D100L D112M	655 655	300 375	295 300	255 255	555 655	205 205	10 10	395 395	200 200	97 115	26·0 26·0	12·0 15·0	11·5 12·0	10·0 10·0	22·0 22·0	8·0 8·0	0·45 0·45	15·5 15·5	8·0 8·0	215 255
R108	D100L D132M	845 845	300 385	295 300	255 280	745 745	205 230	10 10	520 520	200 200	110 150	33·0 33·0	12·0 15·0	11·5 12·0	10·0 11·0	29·5 29·5	8·0 9·0	0·45 0·45	20·5 20·5	8·0 8·0	240 330
R110P	D132S D160L	970 970	385 440	515 540	280 320	870 870	230 265	10 10	525 525	420 420	160 235	38·0 38·0	15·0 17·5	20·5 21·5	11·0 12·5	34·5 34·5	9·0 10·5	0·45 0·45	20·5 20·5	16·5 16·5	350 515
R107NF	D100L D132S	655 655	315 390	345 355	255 280	555 555	205 230	10 10	415 415	255 255	85 120	26·0 26·0	12·5 15·5	13·5 14·0	10·0 11·0	22·0 22·0	8·0 9·0	0·45 0·45	16·5 16·5	10·0 10·0	190 265
R108NF	D100L D132M	845 845	302 385	295 300	255 280	745 745	205 230	10 10	520 520	200 200	110 150	33·0 33·0	12·0 15·0	11·5 12·0	10·0 11·0	29·5 29·5	8·0 9·0	0·45 0·45	20·5 20·5	8·0 8·0	240 330

Notes: 1. The above dimensions are based on 1440 rev/min 3-phase 50 Hz TEFC standard metric motors.
2. Dimensions "C" and "J" give overall height of compressor end without fittings.
3. A fully dimensioned drawing for bedplate mounted machines or bare shaft machines, as required, will be supplied on request.
* Bare shaft machine only.

We reserve the right to alter details and specifications without notice.

CompAir

CompAir Industrial Ltd.
PO box 44 Reavell Works
Ranelagh Road
Ipswich England IP2 0AE

telephone Ipswich (0473) 217901
telegrams Reavell Ipswich
telex 98254

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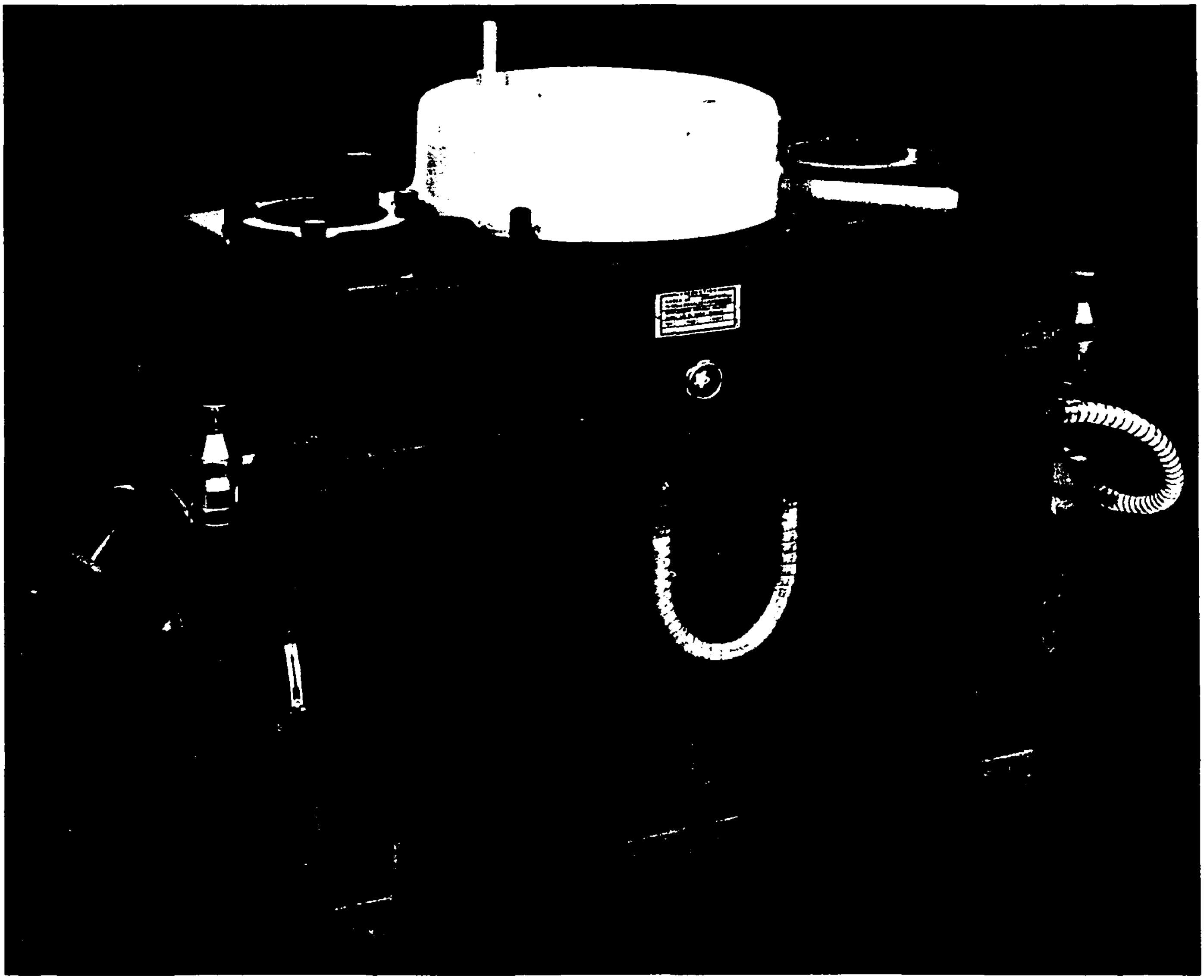
Printed in England
Publication 7010

DECOMPRESSORE VAKUUMPUMPE

APPENDIX V/3



moro® s.p.a.

Casella Postale 217 I- 33170 PORDENONE Tel. (0434) 959501 Telex: 450276

DECOMPRESSORE M9

Il DECOMPRESSORE M9 è particolarmente adatto per **lavori continuativi e gravosi**, grazie al completo **raffreddamento a circuito forzato brevettato**, sia nel corpo che nel rotore stesso.
La semplicità dell'esecuzione è ottenuta con **rotore a due sole lamelle**, valvola d'acciaio a sede piana, fusione del corpo con alettature di raffreddamento, serbatoio olio e deviatore incorporati.
Tali caratteristiche ne limitano al minimo l'usura, la manutenzione e il costo d'esercizio. Non trascurabile la silenziosità e la semplicità di applicazione.

VAKUUMPUMPE M9

Unsere langjährige Erfahrung in der Herstellung von Vakuumpumpen gipfelt in der Entwicklung dieser neuen Type, welche folgende Eigenschaften aufweist:

- hohe Pumpleistung für rasche Evakuierung grosser Tanks.
- Ausgezeichnete Reisskraft.
- **Extreme Betriebssicherheit auch bei stärkster thermischer Belastung** durch Dauerbetrieb infolge der **patentierten Zwangsumlaufkühlung** von Rotor und Gehäuse.
- **Zweischiebersystem** mit Lamellen aus Kunststoff, daher **geräuscharm** und für praktisch alle Medien einsetzbar.
- Integriertes Oelreservoir.
- Eingebaute **Umschaltvorrichtung** von Saug- auf Druckbetrieb ohne zusätzliche Ventile und Anbauteile.

Die neue Bauweise garantiert:

- geringe Unterhalts- und Betriebskosten dank niedrigem Verschleiss,
- niedrigen Geräuschpegel, einfache Montage.

M9 VACUUM PUMP

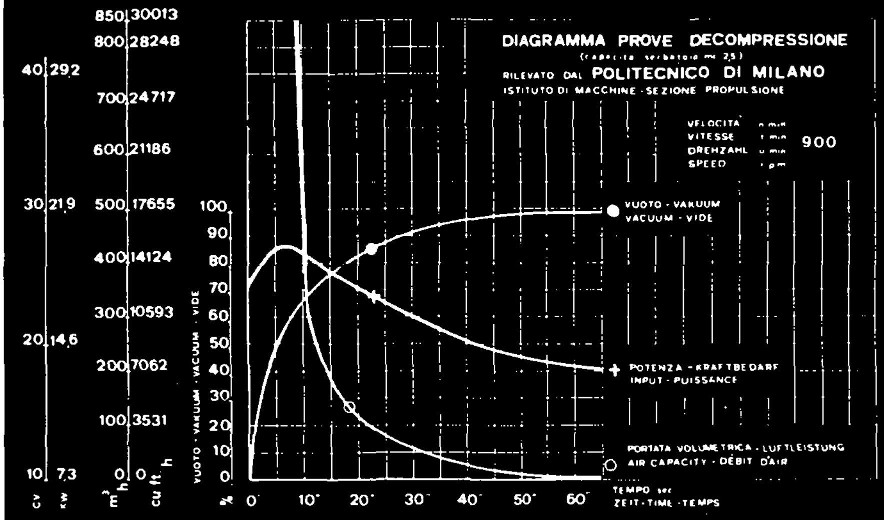
This new addition to our pump range is the result of considerable experience over many years of vacuum pump operation and manufacture.
In addition to the usual high standards associated with MK pump equipment the new M9 vacuum pump has the following special features:

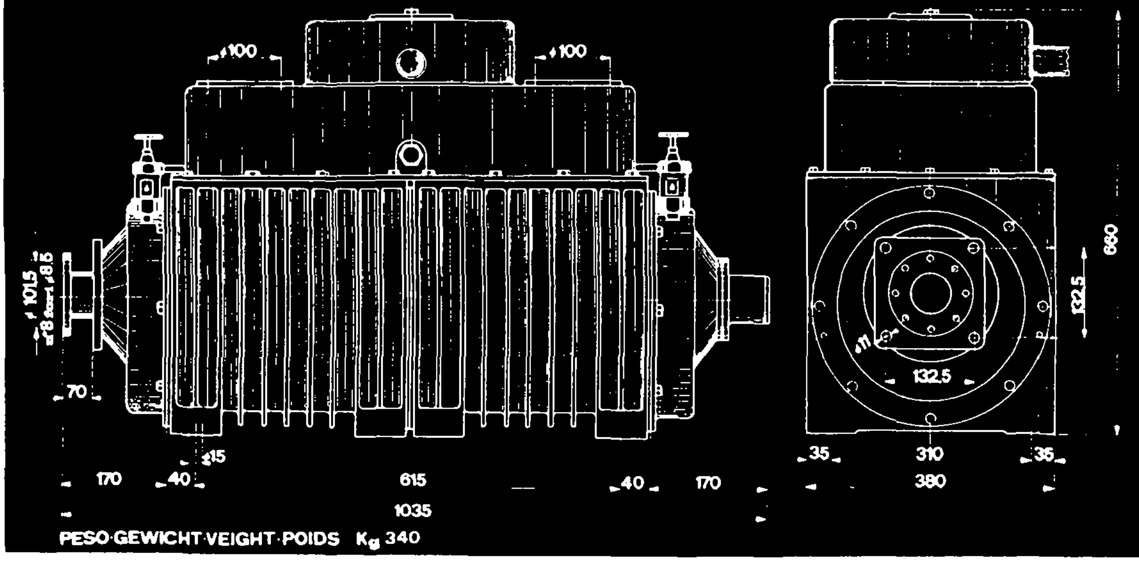
- **patented rotor/housing water cooling system** allowing continuous operation with extreme reliability at high temperatures.
- **Twin blade rotor** with plastic vanes ensuring **low noise levels** and the ability to handle practically all normal materials.
- **High suction capacity** to provide fast emptying bulk storage tanks, etc.
- Unique **change over device** to provide instant change over from suction to pressure without supplementary valve gear.
- Incorporated oil tank.

The new M9 vacuum pump will provide the operator with high operational efficiency, low operating costs, minimum noise levels and easy accessibility for maintenance.

DECOMPRESSEUR M9

Le DECOMPRESSEUR M9 est particulièrement indiqué pour **travaux continus et durs**, grâce au complet et **breveté refroidissement à circulation forcée** tant dans le corps que dans le rotor même.
La simplicité de construction est obtenue par un **rotor à deux palettes**, soupape en acier à siège plan, corps de pompe av ailetage de refroidissement, réservoir à huile et commutateur incorporés.
Ces caractéristiques réduisent l'usure, l'entretien et le coût de exercise au minimum. Ne sont pas négligeables le silence de fonctionnement et la simplicité de montage.





PESO·GEWICHT·VEIGHT·POIDS Kg 340

LIQUID RING VACUUM PUMPS

RPL-SIHI liquid ring vacuum pumps are semi-positive displacement pumps of simple and robust construction. They have the following features:

Almost all gases and vapours can be pumped

The gases being pumped can be saturated with vapour

Compression of the gases being pumped is nearly isothermal

Considerable quantities of entrained liquid can be handled

Reliable operation with minimum maintenance

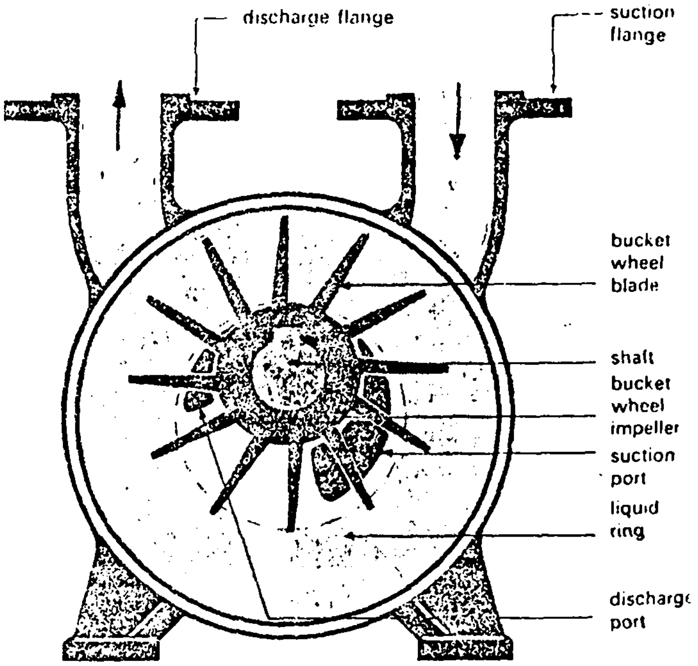
Low noise and vibration levels

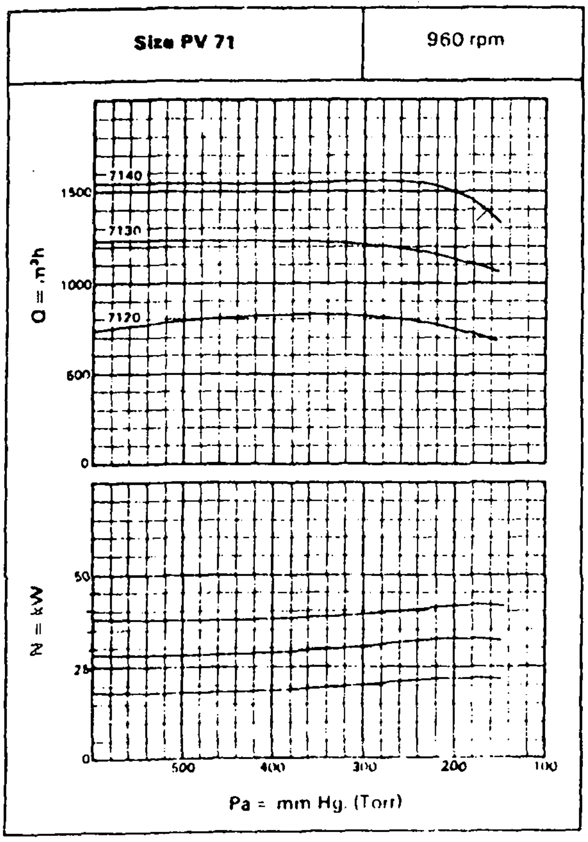
Adaptable to most duties when correct choice of materials of construction and service liquid are made.

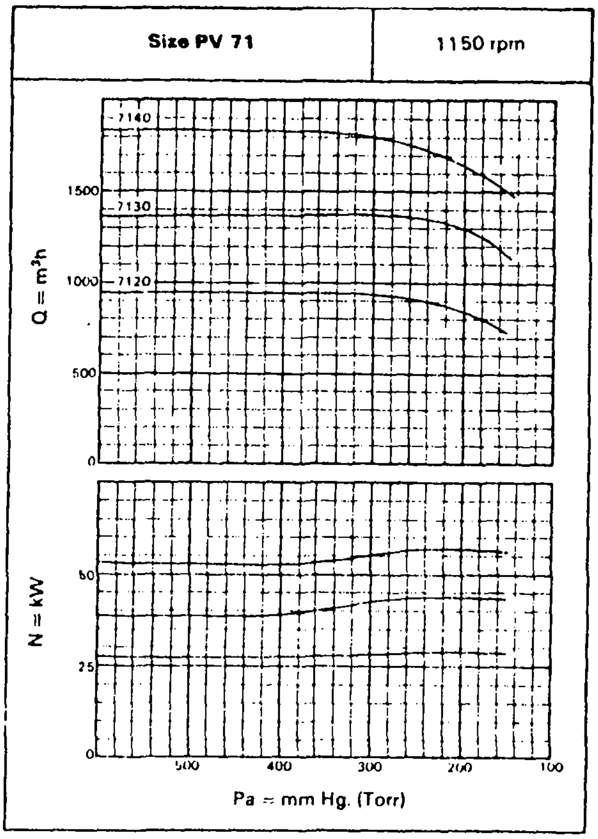
Service liquid need not be a lubricant

Notes

During operation, a liquid ring pump must be continuously fed with service liquid. This is normally water. The service liquid is discharged through the discharge port of the pump together with the gases being pumped. The service liquid can be separated from the gas by means of a service liquid separator (see Catalogue Section A) and then partially recirculated to the pump.







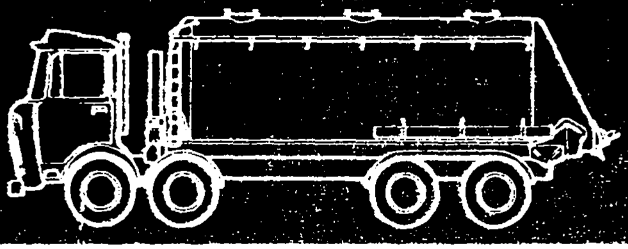
Q_B = Capacity m^{3}h dry attenuated air measured at the suction pressure when using water at 15°C as the service liquid.
N = Power input kW.
Pa = Absolute pressure at the pump suction.
Tolerance – 10%
Barometer – 760 mm Hg

APPENDIX V/6

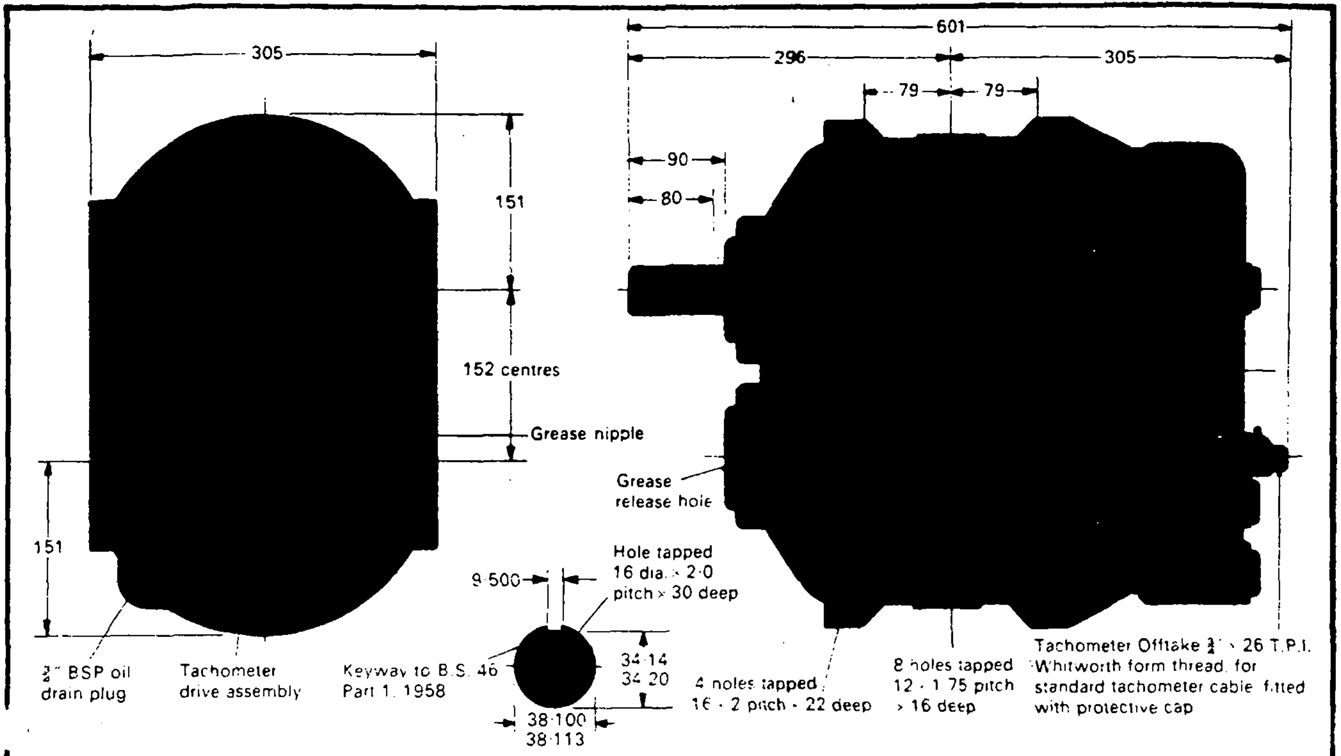
HOLMES POSITIVE DISPLACEMENT AIR BLOWERS

FOR BULK TRANSPORT VEHICLES

TYPE 68 RBT



Peabody Holmes



Type 68 RBT Air Blower – Standard Machine

Type 68 RBT Air Blowers

The type 68 RBS Holmes Positive Displacement Air Blower was introduced in 1965 following an extensive development programme, involving field trials, to meet the specific requirements of bulk transport vehicle builders and users.

This machine proved to be so successful in operation that many of its design features were adopted by competitors. A continuing development programme has, however, meant that the type 68 air blower has remained ahead of its rivals. This is clearly shown by the fact that many hundreds, including the later RBST machine, are in service on vehicles and in land based applications throughout the world. The RBST machine incorporated a specially designed and patented controlled lubrication system for the gears.

The RBT machine described in this brochure is a further development which, whilst retaining many of the earlier design features such as the controlled lubrication system and an optional speed increasing gearbox, incorporates many new ones bringing additional user benefits. The most important of these is that the operating range, both speed and pressure, has been extended. This helps to combat environmental pollution problems associated with dust and noise.

User Benefits

★ With a relief valve setting of 1,050 m bar (15 psig), the minimum recommended speed is now 1,000 rpm, providing low air volume discharge with resultant low noise levels and engine speeds. The reduced air volume also minimises dust nuisance. If required, the relief valve can be set for 1,250 m bar (18 psig) with a minimum speed of 1,450 rpm. This helps unloading when poor silo conditions or badly laid out discharge pipework are encountered.

★ A hydraulic pump with a compact drive arrangement is available for vehicles having a single power take-off aperture or a limited power gearbox, and also for direct coupled powerpacks.

★ The blower can be operated with a longitudinal inclination of up to 10° without risk of oil starvation: this is of particular importance when the vehicle is not standing on level ground.

★ There are no wear tips or inserts on the impellers which need to be bedded in after installation, and which might subsequently become detached or damaged causing the vehicle load to become contaminated by foreign matter. Air gaps at each end of the cylinder ensure that there can be no contamination by oil or oil vapours

★ Centre timing permits operation in either direction – vertical or horizontal air flow.

★ All machines are works tested from cold direct onto 1,250 m bar (18 psig) at less than the minimum recommended speed before despatch. A volumetric acceptance test is also carried out.

Specification

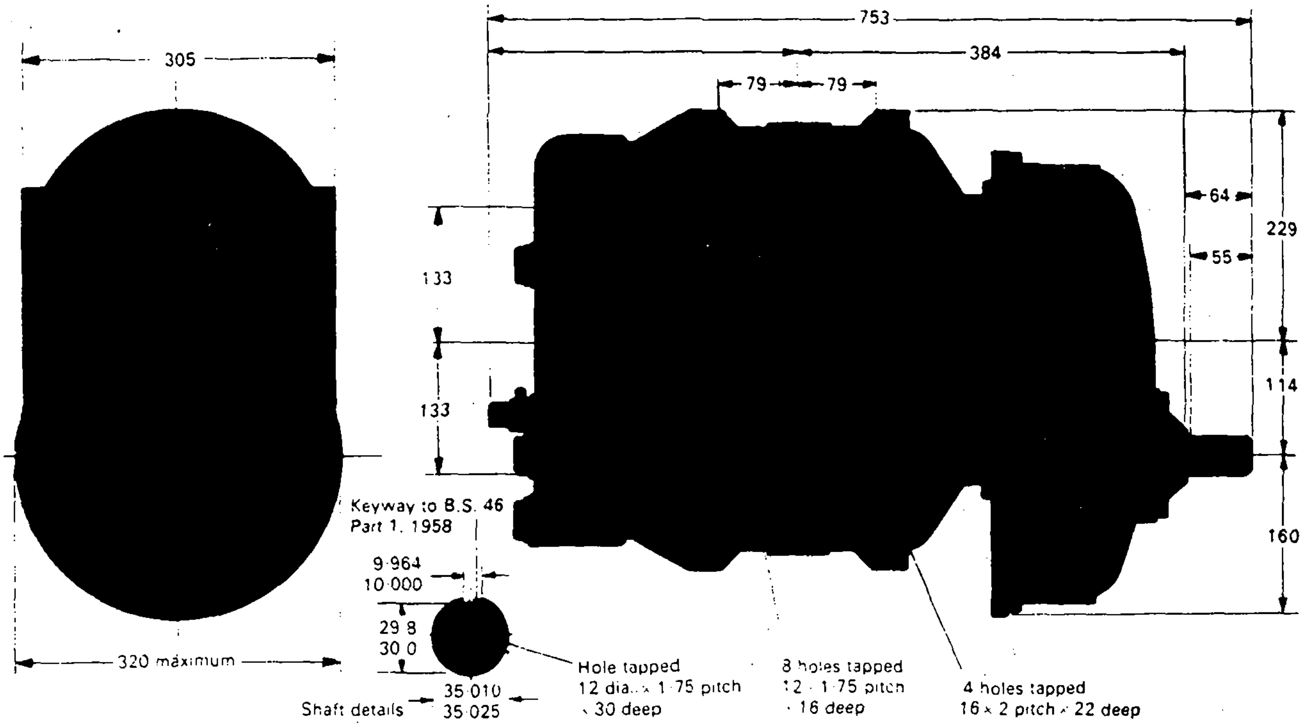
Casing: The cylinder and headplates are manufactured from cast iron.

Impellers and Shafts: The impellers and shafts are of one-piece construction, with axial location and centre timing.

Gears: The straight spur timing gears are taper mounted onto the shafts, and operate in a totally enclosed gearcase.

Bearings: The bearings are of generous proportions to give long operational life. Grease lubricated angular contact locating bearings are used at the drive end. Roller bearings at the gear end are splash lubricated from the gears.

Lubrication: A gear trough controls the lubricating oil system, allowing the blower to operate at maximum speeds without the need for an oil pump. Oil throwers are fitted



Type 68 RBT Air Blower fitted with a Speed Increasing Gearbox

behind each gear end bearing: these do not require maintenance.

Air gaps: The blower is constructed with an air gap at each end, between bearing and cylinder, to ensure that the delivered air cannot become contaminated by oil or oil vapours.

Timing: When a standard machine is to provide a horizontal air flow, the top shaft is extended for the drive. If the machine is mounted for vertical air flow, the drive shaft is on the right. Centre timing enables the blower to operate in either direction. If the machine has to have a bottom or left hand shaft extended, all that needs to be done is to turn the gearcase and trough through 180°. The position of the shaft is given when looking at the machine from the drive shaft end.

Tachometer Offtake: A mechanically driven tachometer offtake is provided on the gearcase cover. Whilst this is normally driven from the bottom shaft on a standard machine, it can easily be changed to the alternative top position.

Type of Drive

The type 68 RBT machine is suitable for direct drive from the power take-off; belt drive; independent drive from a petrol or diesel powerpack or by a hydraulic pump and motor. A V-belt drive cannot be used if the blower is fitted with a speed increasing gearbox, has a hydraulic pump or if it is to operate at pressures in excess of 1,050 m bar (15 psig).

Speed Increasing Gearbox

The optional speed increasing gearbox is manufactured from cast aluminium. When fitted it becomes an integral part of the blower, but has a lubricating oil system separate from that of the blower timing gears. Either 2:1 or 1½:1 speed increasing ratios are available enabling the blower to be matched to a wide range of engine, gearbox and power take-off systems.

Hydraulic Pump

To power the tipping gear and/or a hydraulically driven rotary seal or some other device, a coupling and carrier can be fitted to the type 68 RBT blower to drive a close coupled hydraulic pump. The standard carrier will accept the Commercial Shearing P30 series pump. The addition of an adapter enables a WPA61 Edbro Pump to be fitted. Both of these pumps will deliver a nominal 45 litres/minute (10 gpm) against 103 bar (1,500 psig) when driven at 1,500 rpm.

When selecting a power take-off, a further 15 bhp beyond that required by the air blower should be provided.

The versatility of blower mounting is not impaired in any way when a pump is fitted, but a pump cannot be fitted to a blower which has a speed increasing gearbox or if it is driven by V-belts.

The maximum speed of the blower when fitted with either type of hydraulic pump should be limited to 1,800 rpm and the maximum relief valve setting to 1,050 m bar (15 psig).

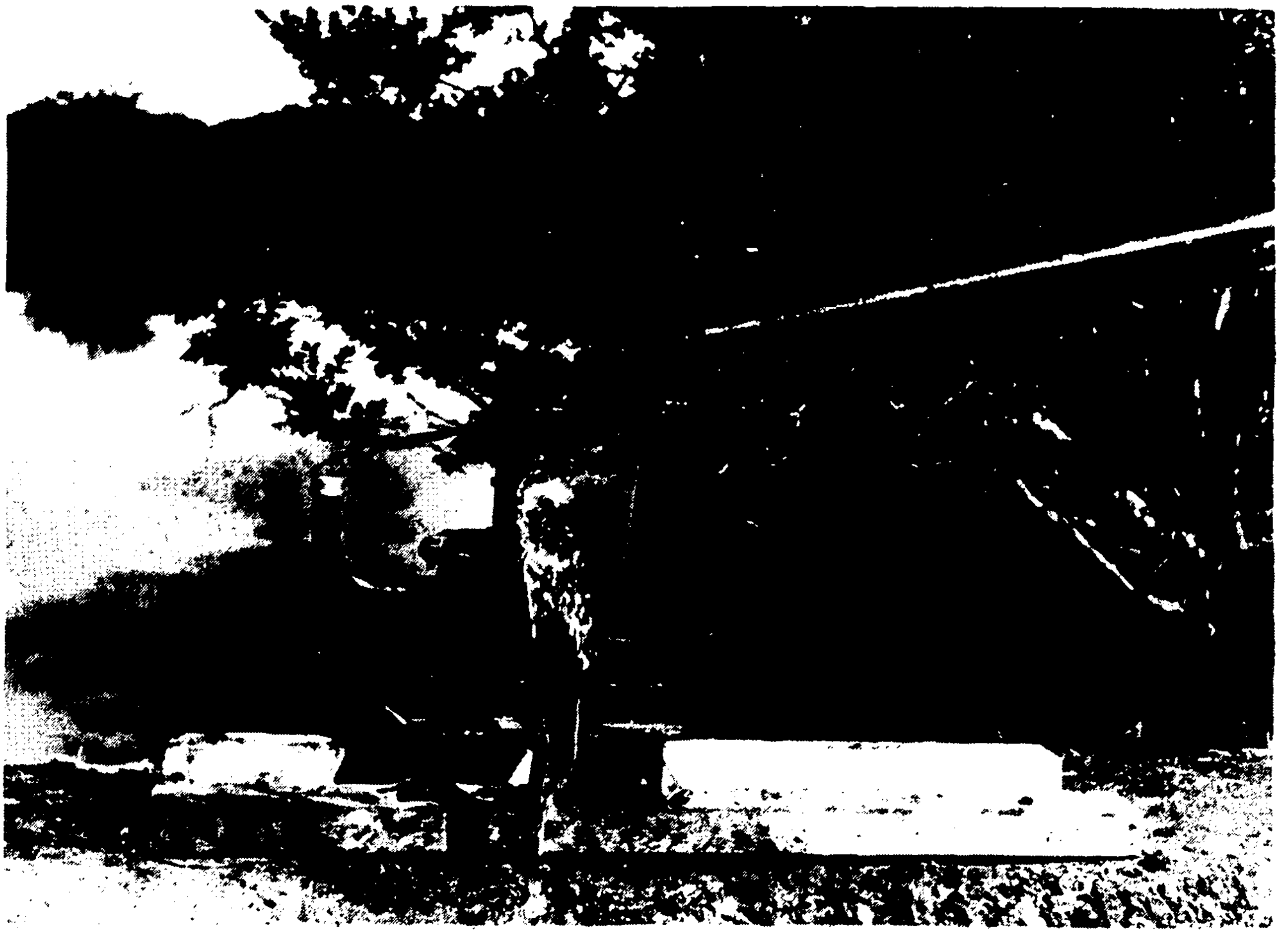
Weather Shields

For applications demanding maximum cleanliness, a splash guard and covers to protect the air gaps from road dirt and spray can be supplied.

DUNLOP ZIMBABWE LIMITED

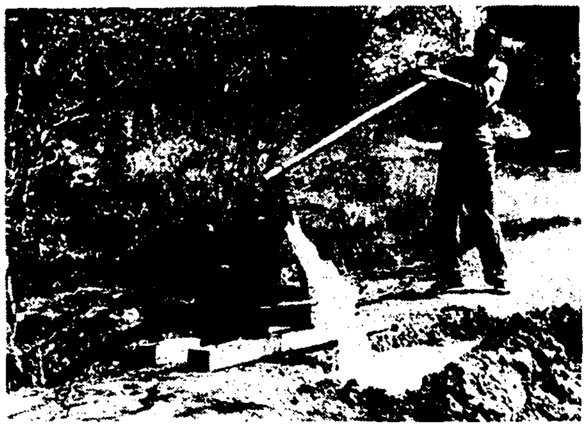
INTRODUCING THE

BUMI PUMP



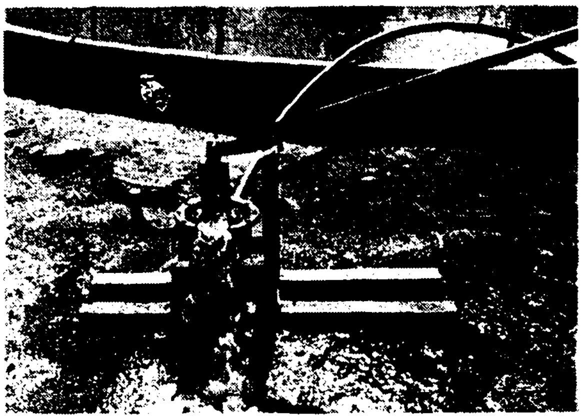
Dunlop have especially developed the Bumi Pump to meet the irrigation needs of Zimbabwe's subsistence cultivators, and the varied requirements of the commercial farmer.

This robust, versatile, hand-operated pump, with only three wearing parts, has been designed and manufactured in Zimbabwe for use under the harsh conditions commonly encountered in developing countries.



IRRIGATION

The Bumi Pump is capable of irrigating over a hectare of land throughout the year. Typically, water is pumped either from a perennial water body, or a dry river bed (sand abstraction) into a canal for furrow irrigation.



MISCELLANEOUS USES

Although developed for irrigation, the pump has a variety of uses, ranging from dip tank maintenance to excavation de-watering. The rubber components have been especially formulated to resist chemical degradation.

PERFORMANCE

Capacity:	4 litre/stroke
Head:	10 m (6 m suction)
Inlet:	2 inch Ø hose spigot
Outlet:	fabricated to request

For further information contact:

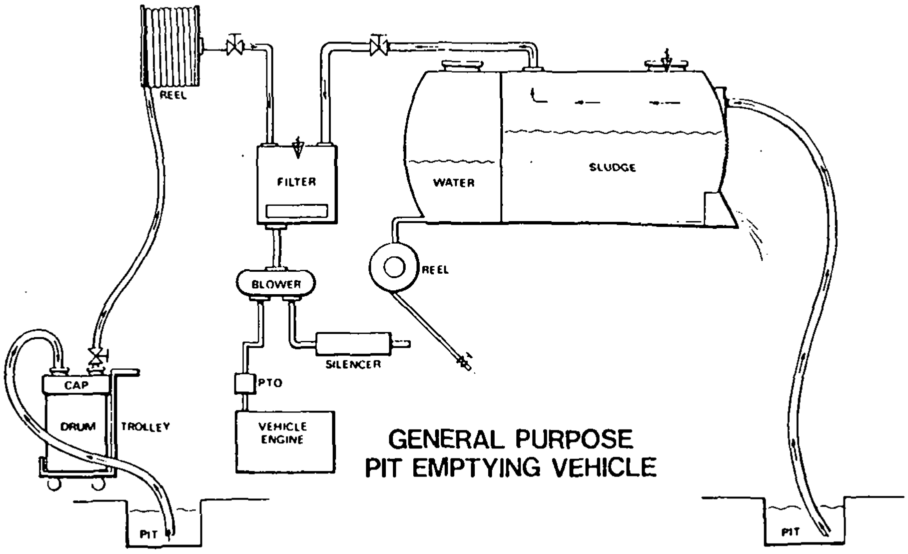
IRRIGATION MANAGER
DUNLOP ZIMBABWE LIMITED
P.O. BOX 1200
BULAWAYO

TELEPHONE: 71981
TELEX: RH 3147

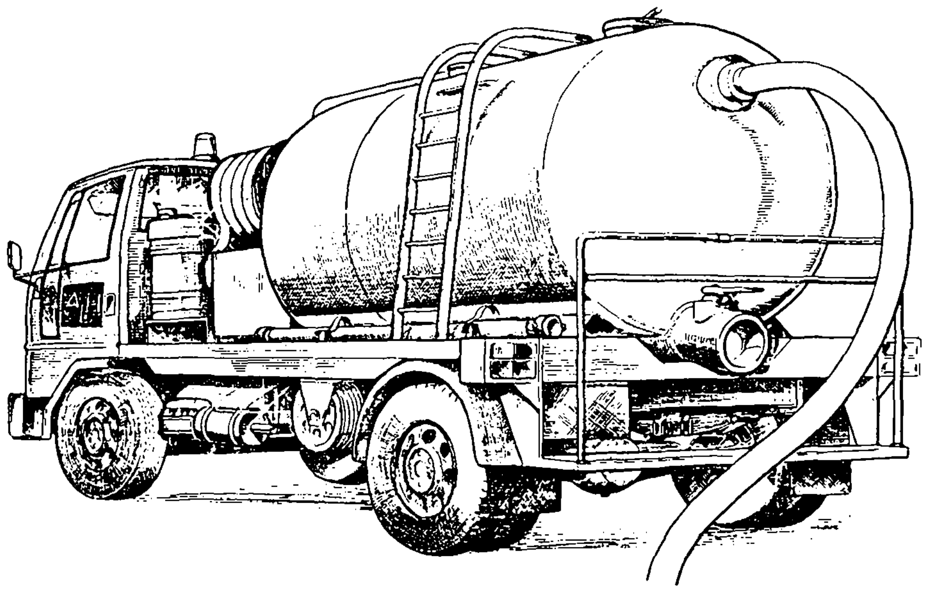
Remote System Proposed by ALH

Specification:

- 4.5 m^3 slurry tank
- Large 225 mm outlet on rear of tank for sludge disposal
- clean water tank
- 75 mm hose to connect the tank with the remote unit
- 100 mm hose for removing the content of the pits
- hosereel for 75 mm air hose
- suction hose should have aluminium nozzle
- quick hose couplings
- exhauster and clean water pump driven by PTO
- holding facilities for 3 drums and a hand trolley
- standing platform for crew members
- slurry separator
- level gauge



GENERAL PURPOSE PIT EMPTYING VEHICLE



INSPECTION

Daily inspection

Before work:

Check:
- Oil level in the vacuum pump
- Oil level in the oil cooling tank
- Oil level in the hydraulic tank
- Pump oil cooling radiator
- Hydraulic oil cooling radiator

After work:

Drain:
- The sludge separator
- The oil separator

Weekly inspection

Check:

Check and clean the safety guard valves for overfilling the tank. Check also that the gaskets are in close contact with the seats and that the steel balls (6") are undamaged.

The hydraulic system for leakages (tighten the couplings)

Check and grease the power take-off shafts

Fortnightly

Clean the vacuum pump as follows:

- Suck 5 l Diesel oil through the valve of the suction pipe by running the pump at low speed. Wait approx. 2 min. before adding another 5 litres Diesel oil to the pump. After running the pump for approx. 5 min., add 1/2 l lubrication oil. After a few minutes, drain the oil separator. Put a bucket under the drain valve.
- Grease the unit at the same time as the chassis.

Yearly

Change the hydraulic oil and the hydraulic filter

Change the cooling oil at the same time or if required

Clean the cooling oil filter

BEFORE USING BREVAC CARRY OUT THE FOLLOWING DAILY/WEEKLY MAINTENANCE CHECKS

	DAILY	WEEKLY
1. Check chassis engine water level	X	
2. Check chassis engine oil level on dipstick	X	
3. Check tyre pressures (including spare)		X
4. Check windscreen water bottle level	X	
5. Check hydraulic oil tank level (tank down - not tipped)	X	
6. Check fuel oil level	X	
7. Check wash water tank level	X	
8. Check vacuum pump water tank level	X	
9. Check that the inspection hatch is closed and catches are tight	X	
10. Check that rear door is closed and secured properly	X	
11. Drain water from air brake reservoirs (by pulling on wire loops)	X	
12. Check all lights, indicators and horn		X
13. Check that all hoses coupling rings and accessories are present and secured in the hose trays	X	
14. Drain vacuum pump water tank and flush out with water		X
15. Remove vacuum pump water filter and clean		X
16. Remove wash water filter and clean		X
17. Check fuel oil water trap jar for water/ sediment - clean if necessary		X

18. Grease rear door handwheels
19. Grease tipping ram pivots
20. Grease rear tank pivots

} at each service when changing engine oil (every 7500 km)

Yearly

- Change hydraulic oil after 1500 hours or 1 year
- Change hydraulic filter when indicator shows red

Every 2 years

- Check vacuum pump bearings after 3000 hours or 2 years

ALH Systems Limited
Station Road, Westbury, Wiltshire BA13 4TN England Telephone: Westbury (0373) 864744 Telex 449726

MAINTENANCE INSTRUCTIONS

The following are recommendations for periodical checking as per manufacturers instructions:

Daily

1. Check lubricant level in Lister diesel engine.
2. Check drive between engine and exhauster.
3. Check that rev. counter is recording correct r.p.m.
4. Check cleanliness of 4" suction hose.
5. Check 3" hose connecting clips.

Weekly

1. Check Vacuum Exhauster oil level and the gearcase for any leaks. (Please note: the vehicle should be stood on level ground with the blower stationary). The oil level filler plug should be removed and if level is correct, oil will run from the hole.
2. Check diesel engine for oil leaks.

6 months or 400 hours

1. Check filter bags in filter chamber.
2. Drain and replace oil in Lister diesel.
3. Drain and replace oil in Vacuum Exhauster.

Measure Protocol

site number 45

equipment ROLBA

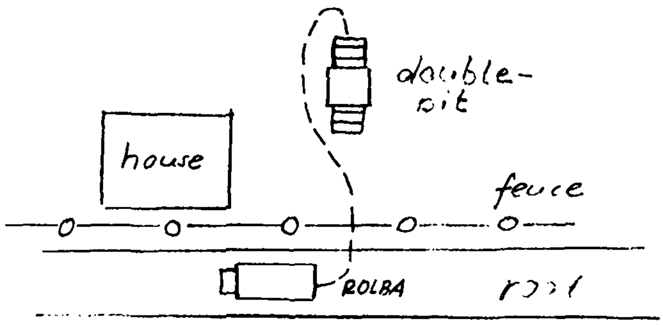
distance

date/time 10. 1. 84

weather sunny

address 04195 Old Naledi

Site Layout:



Distances:

pit equipment 10 m

pit house 6 m

pit road ( ) 9 m

pit road ( )

Latrine:

latrine type double-pit latrine

year of building 1976

year of last desludging never been emptied

flies (identify) no

odour no

condition clean/dirty dirty

comments on access good, through removable slabs

width 0,9 m

length 1,6 m

depth a) 0,9m b) 1,7 m

ϕ inlet removable slabs

pit lining no

surface drainage no

superstructure concrete block

proposal for possible improvements of pit design pit should be lined

other comments

Usage Data

number of persons using the latrines on an average

children ....5.. adults ..5..........

variation of usage ....continuous..........

anal cleansing (sanitary napkins) ....news-paper..........

other comments ....

....

Pit Content

scum layer yes/no ....no → liquid / sludge..........

pit was overflowing ....no..........

other content ....bottles, rags, paper..........

depth of groundwater table ....

maintenance facilities lime/disinfectant etc. ....no..........

does greywater lead into pit yes/no ....no..........

other comments ....

....

Behaviour of Sludge

	type of sludge	% water	% volatile	% non-volatile	density kg/dm^3	temp.
local equip. after 1st trial						
local equip. after 2nd trial						
after ~~AIH/BRE~~ Rolba	med.$^+$	45.8	7.3	46.7	1.582	26°C

other comments ....

....

Performance

		local suction unit		~~ALH/BRE~~ Rolba
		1st trial	2nd trial	
1	air flow ($m^3/_{min}$)			17
2	rotor speeds (rpm)			800
3	vacuum rating (bar)			0.8
4	diameter of suction hose (mm)			4"
5	length of suction hose (m)			12 + 2
6	total volume emptied (m^3)		~0,8 · 0,9 ·	1,6 = 1.2 m³
7	set up time (min)			3
8	emptying time (min)			5
9	dismantling and washdown time (min)			5
10	total time (7÷9+16)			13
11	emptying rate $^6/_{10}$ ($m^3/_{min}$)			0.092
12	effect. flow rate in suction hose $^6/_8$ ($m^3/_{min}$)			0.24

Emptying Procedure

		local suction unit		~~ALH/BRE~~ Rolba
		1st trial	2nd trial	
13	hose shaken yes/no			yes
14	air bleed system yes/no			yes (plug. drag)
15	use of a fluidisat. equip. ?			yes
16	mixing time (min)			approx. 2 min
17	amount of water added (l)			approx. 100 l
18	blockage frequency			////
19	any material left over after emptying ?			sand
20	easy to remove ?			no
21	fuel consumption per day			
22	number of crew members required including driver			4

23 discharging time .... 10 min

24 distance to the disposal site .... 5 km

25 location of disposal site ....

26 emptying charges if any ? ....

27 reaction of pit owners regarding charges ? ....

Swiss Federal Institutes of Technology

IRCWD WHO-INTERNATIONAL REFERENCE CENTRE FOR WASTES DISPOSAL
associatetd with
Swiss Federal Institute for Water Resources and Water Pollution Control

Director:
Prof. Dr. Werner Stumm

Mailing address:
IRCWD
Ueberlandstrasse 133
CH-8600 Dübendorf
Switzerland

Telephone (01) 823 50 18/17
~~Telex EMPA CH 53817~~ Telex 53 287 EAWA CH

Your ref: Our ref: RSCH/SP Dübendorf: 14 October 1985

Dear colleagues,

Please find enclosed a copy of the full report on the field tests with emptying equipment in Botswana.

We think that these field tests were an important step in establishing the technical limits of the different equipment used in handling different types of sludges. However, some questions still remain unanswered and require further work:

a) The development of an alternative system is necessary for areas where tankers cannot get closer than 60 m to the pits, and where medium or high-viscosity sludge has to be handled. Under these circumstances, the development of a system with a remote unit is suggested. Based on our present knowledge about typical location of and accessibility to latrines in urban areas of developing countries, a draft specification for such a remote system is given in the report (see section 10.2, page 64).

b) The tests in Gaborone which lasted 4-5 months could not answer the crucial question of how well the equipment operates over a long-term period under difficult conditions. Therefore, the BREVAC tanker, the ROLBA tanker and the remote system to be developed, should be tested for at least one year under real-life conditions as encountered for instance in many African cities.

Since this type of work is outside IRCWD's scope, no further specific work in this field is planned for the time being apart from an advisory and coordination task of the on-going work in different parts of the world.

Please inform us if you know of any implementing activities in the field of pit emptying so that we can keep people informed.
With best regards.

Sincerely yours,

R. Schertenleib
Director IRCWD

Encl.: mentioned.

12.82 18817/3