PIT LATRINE EMPTYING

by

S.K. RUNYORO

A Project Report submitted in partial fulfillment of the requirements for the award of MSc of Loughborough University of Technology

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Supervisor: Mr John Pickford, MSc, ACGI, FICE, FIPHE
Department of Civil Engineering

CERTIFICATE OF AUTHORSHIP

"I certify that:

(i) all quotations (including figures) and direct reference to published source information are identified by reference.

(ii) all laboratory work, field work and computer programming has been carried out by me with no more assistance from members of the Department than has been specified on the Project Details form except that.

(iii) all assistance which I have received in addition to that set out on the Project Details form is indicated below and referenced in the report".

Signed S. Rumpon

Date September 1981

WEDC	PROJECT DETAILS	MSc COURSE
Student Name SEMU K RUNYORO	Supervisor MR JOHN PICKFORD	Moderator MR COLIN SAYLES

Title

PIT LATRINE EMPTYING AND NIGHTSOIL DISPOSAL TECHNIQUES

General description

Problems associated with the present methods of emptying pit latrines and disposal of their contents as practiced in most of the developing countries are to be studied and proposals for modifications put forward, particularly relative to vacuum tankers, hand/diesel powered diaphragm pumps and various treatment/disposal techniques

Equipment

State major items of existing equipment needed and if it is likely to require maintenance.
If new equipment is to be constructed complete a workshop requisition form and provide a drawing.
If equipment/material is to be ordered, state cost and delivery time.

NONE

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SUMMARY

In this report, various methods of nightsoil collection, treatment and disposal as practiced in different parts of developing countries are reviewed.

The discussion of problems arising from employing local methods and vacuum tankers for pit latrine emptying is confined to the area in which the author has had an experience.

Proposals for modification of the present vacuum tanker and diaphragm pump designs for effective emptying operations are put forward after having studied the composition and other main properties of pit latrine contents.

Further, discussion of two types of nightsoil treatment which are thought to be feasible in the study area is made.

The involvement of municipal authorities and community participation in a successful operation of the whole system are also covered.

Finally, conclusions and recommendations are drawn from the study carried out.

DEFINITION OF RHEOLOGICAL TERMS USED

Apparent viscosity:	The quotient of shear stress divided by rate of shear when this quotient is dependent on the rate of shear.
Flow curve:	A curve relating stress to rate of shear
Power-law fluid model:	A model characterised by a linear relationship between the logarithm of the shear stress and the logarithm of the rate of shear in simple shear flow.
Rate of shear:	The change of shear strain per unit time.
Reynold's number:	The product of a typical length and a typical fluid speed divided by the kinematic viscosity of the fluid. It expreses the ratio of the inertia forces to the viscous forces.
Rheology:	The science of deformation and flow of matter, critical factors being elasticity, viscosity and plasticity.
Shear thinning:	A reduction of the viscosity with increasing rate of shear in steady flow
Thixotropy:	A rheological property of fluids and plastic solids, characterized by a high viscosity at low stresses but a decreased viscosity when an increased stress is applied.
Yield point:	The point on the stress/strain curve corresponding to the transition from elastic to plastic deformation.
Yield stress:	The stress corresponding to a yield point
Hysteresis:	The property of a material or body whereby different values of a response are produced for the same value of the corresponding stimulus; according to whether that value has been reached by a continuously increasing change or by a continuously decreasing change of stimulus.

1.0 INTRODUCTION

In the practical needs of a developing economy, protection of public health should be given a high priority, as communities expanding without provision of adequate excreta removal facilities results in high incidences of enteric diseases, debility, high costs of medical treatment and reduced productivity.

A waterborne sewage collection and treatment system is probably the best ultimate solution for any country or community, but even in an economy as developed as Japan's, installation of a sanitary sewage system is not simply a matter of putting in pipes once funds have been made available.

The sewage system requires plumbing adjustment, increased water supply for new flush toilets, sewer to house connections which must be installed at the house owner's expense, high capital, operation and maintenance costs, a high level of municipal involvement in ensuring proper running of the system. There is also a tendancy for delay between the start of construction and the actual service to a significant number of people through private connections.

All these and some other factors suggest the adoption and development of low cost sanitary systems in most areas of developing countries where the economy, skilled manpower, water supply and oth er associated resources are limited.

There are various methods of excreta disposal currently employed in different parts of the world. The pit latrine is the most widely used system in developing countries today.

With time of usage, the pit latrines fill up. The speed of filling depends on the number of users, type of diet, quantities of other materials entering the latrine depending on whether water is used for anal cleaning or other materials such as paper, stones and maize cobs are used for the same purpose; and the rising of the ground water table during the rainy seasons.

The traditional practice of digging a new pit when the first one is full may be impracticable in high density suburban areas due to a growing shortage of land created by development. New housing plots tend to become smaller. Rebuilding of the latrine every few years is wasteful of effort and material resources and can not be afforded by the majority of the population.

One solution to this problem could be to empty pits for re-use rather than excavating new ones.

There are various ways of emptying latrines practiced in different parts of the world, the details of which are discussed in the text.

Methods of treatment and disposal of excreta are also discussed and hygenic inexpensive and simple alternatives appropriate for developing countries are proposed.

As very little work has been done in this field, the proposed methods require detailed research work and field tests in order to achieve an ultimate solution so that a large population using pit latrines and other similar systems in developing countries can be served with minimum health risks.

The study of problems associated with pit emptying is particularly based on experience gained in Tanzania; thus the proposals for modification and excreta treatment and disposal techniques are confined to areas with similar conditions.

1.1.0 EXCRETA DISPOSAL METHODS - (General)

There are four principal elements in excreta disposal systems namely:-

a) Defecation area: This could be a latrine or some other receptacle to hold the excreta, where there are no latrines, a defecation area may be field or other waste ground.

b) Removal of excreta to some other container or the replacement of a full container by the empty one.

c) Transportation System for moving excreta to a disposal or treatment area

d) Treatment process and disposal or reuse.

The chart summarising the methods is shown in Figure 1.

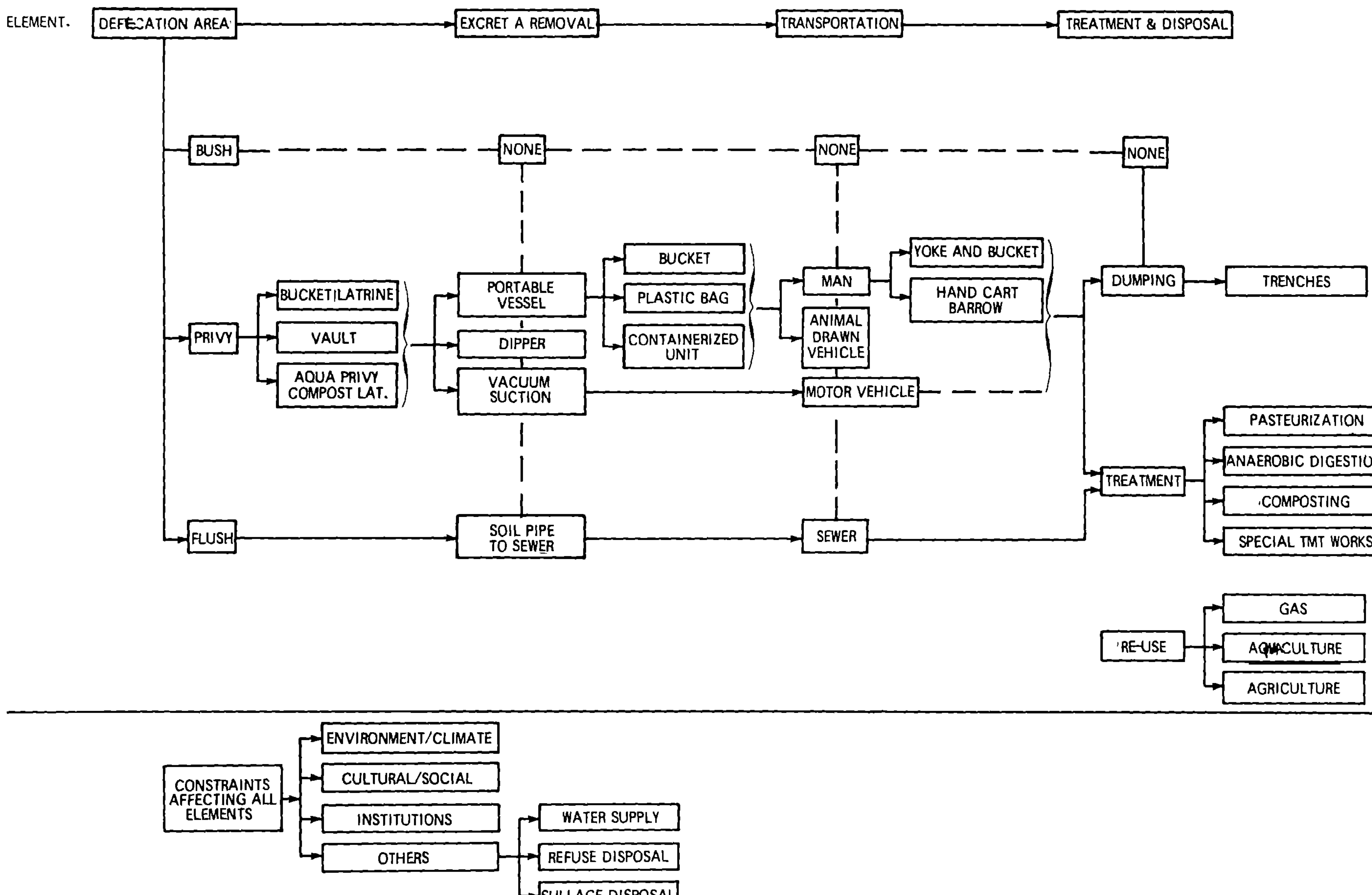
Various countries have different excreta disposal methods depending on cultural, social and environmental factors, level of technological advancement and the economy of a country.

Some of the methods used and their social and health impacts on operatives and the whole community are discussed.

1.1.1 BUCKET LATRINE

This system is typical of many parts of East Asia and Africa, where removal of excreta is either replacing full buckets from the latrine by empty ones, or tipping the latrine bucket into separate carrying buckets. The buckets are transported by suspension from a yoke slung over a man's shoulder. This method can be very unhygienic due to the high probability of spillage during removal and transportation, and thus is an offensive

Fig 1· PRINCIPLE ELEMENTS IN CARTAGE AND CARRYING SYSTEM FOR EXCRETA REMOVAL



procedure that is detrimental both to environmental and health conditions, but it has an advantage of offering badly needed employment as it is basically labour intensive.

In India, special handcarts which can carry six buckets (with close fitting lids) at a time, have been developed. This will reduce spillage and improve transportation efficiency.

In Sydney, Australia, Sweden and Nigeria bucket container systems operate with various transportation and disposal methods.

1.1.2 CONSERVANCY VAULTS

(a) In Korea, Taiwan and other parts of East Asia a dipper with a long handle is used to empty small vaults by ladling their content into buckets for carrying on a yoke and disposed of on farms and fish ponds (Fig 2). Again this method has the danger of spillage possibilities but it provides employment.

(b) Vaults may be emptied by hand/diesel operated suction pumps fitted to tanks carried by hand carts, small motor vehicles or animal drawn vehicles.

(c) In Japan, Taiwan and Korea, the emptying of vaults and transport system is completely mechanised by using vacuum trucks.

This method is quite efficient and free of health hazards resulting from spillage but it involves high capital, operation and maintainance costs as compared to other cartage systems discussed in (a) and (b).

(d) In Botswana, double pit latrines have been developed and constructed. The twin chambers are designed to be emptied by suction hose or manually with a long handled shovel.

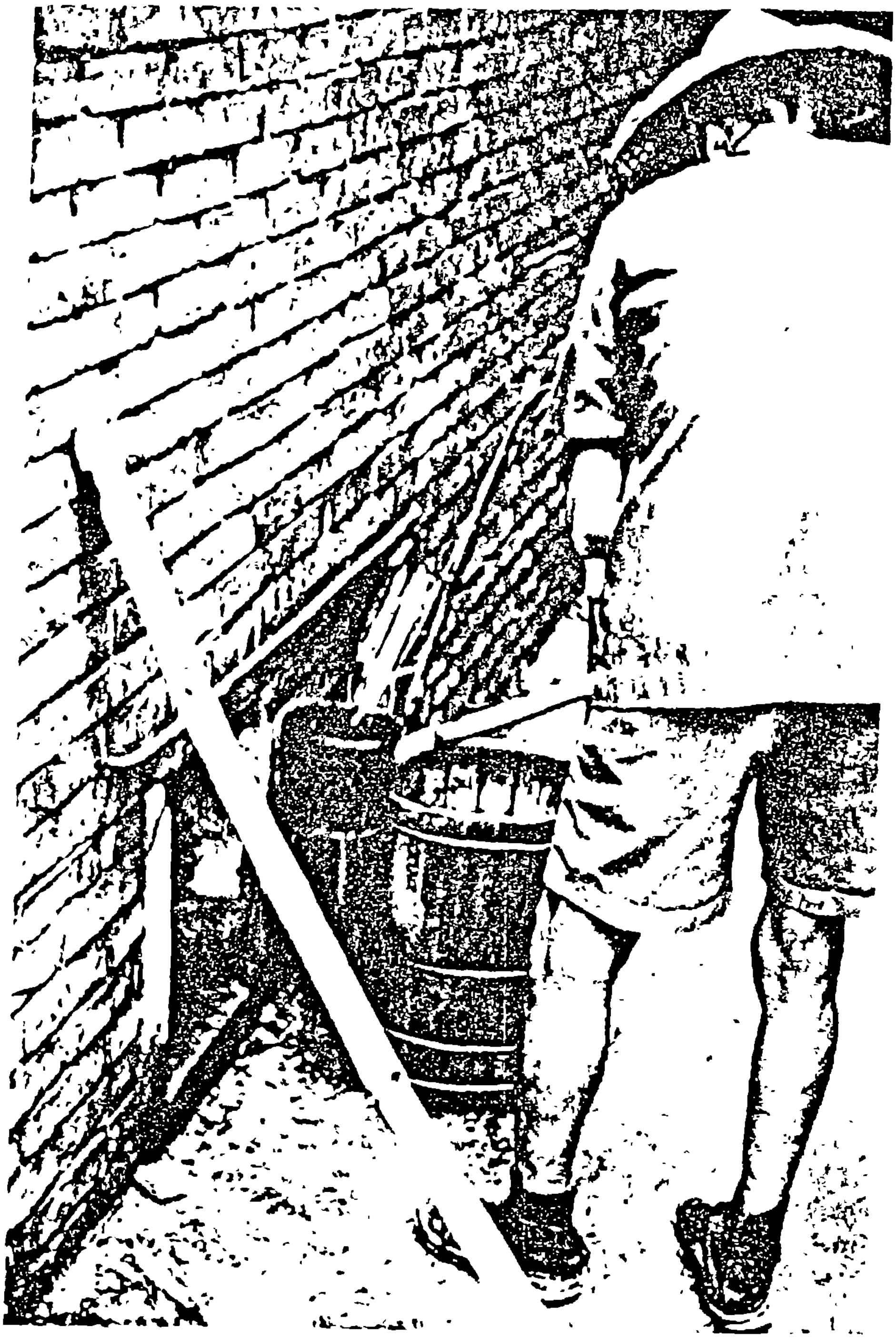


Figure 2: Nightsoil Collection by Dipper and Bucket in Taiwan

(Photograph by: M.G. McGarry)

(e) In Tanzania traditional pit latrines which are found in urban areas are emptied by either of two methods:-

(i) Using a vacuum tanker. The emptying is not effective with this method as itis only the liquor which is decanted leaving the solids to accumulate at the pit bottom. There is blockage in suction pipe due to pieces of clothes and other domestic refuse which are thrown in pits being sucked in. Also there is a tendency for operatives to declare the truck to be full when it is actually one third full or sometimes claim the tanker performance to deteriorate when the tanker fills up.

(ii) The second method is a local one in which the cover slab of a full pit is partly opened up, the contents are scooped with buckets and spades, then disposed of in a trench dug nearby which is later on covered with soil. Finally the pit slab is reconstructed.

1.2.0 PROBLEMS ARISING FROM EMPLOYING CURRENT EMPTYING AND DISPOSAL METHODS IN THE STUDY AREA

1.2.1 LOCAL METHOD

Local methods of pit emptying are executed by self employed local contractors.

The method involves breaking and part removal of concrete cover slab and scooping out the excreta with buckets spades and hoes.

The operatives wear neither protective clothes nor boots. This results in health risks of being infected by hookworms and the possibility of ingesting pathogenic organisms if thorough hand washing using disinfectants is not practised, which is usually the case.

The emptying operation may take 2-3 days, thus resulting in odour and fly-nuisance transmitting all sorts of diseases, and inconveniences

caused to the users as they have to visit neighbouring latrines until the reinstatement of the latrine.

The disposal method, being burial, may cause a number of problems viz.(i) it is obnoxious and is a source of fly nuisance (ii) may contaminate the ground water by leaching and percolation. (iii) if not well covered the materials can become a potential carrier of a number of enteric diseases such as cholera, typhoid, dysentry, infectious hepatitis, helminthic diseases and amoebic dysentry.

The costs for services and materials for reconstruction of the slab have to be borne by the latrine owner.

The charges vary from one contractor to the other because they are not centrally organised. Thus at times the amount may be too much for a latrine owner, so that he may be compelled to use the flooded latrine till such a time when the required amount of money is available. In so doing health risks are increased and there is discomfort to users.

1.2.2 VACUUM TANKER

The municipality puts much emphasis on emptying cesspools but little attention is paid on pit latrine emptying using vacuum tankers. This reluctance is attributed to the hard pan of sludge (consolidated layer of excreta) at the bottom of the pit and high consistency of excreta in subsequent layers. Thus effective operation requires flooding the full pit with water and then extracting the diluted contents.

The trucks do not have separate compartments for carrying water, so the required water is obtained from respective households.

This has two drawbacks. First water is normally a scarce resource and secondly the effect of its addition will result in an increased volume of material to be sucked. Hence some other methods of emptying pits without addition of water should be sought.

The vacuum tankers do not readily decant the liquor from the pit due to blockage which occurs when the suction pipe is placed onto the sludge layer. It gives the impression of "bulking" the sludge together to cause blockage in the first length of suction pipe. Also blockage is caused by large sized materials viz. non-excreted matters thrown in pit that cannot be sucked through a 100 mm diameter pipe.

Some latrines have too small squating holes to enable accessibility of suction pipe into the pit and there are no other provisions to effect emptying, in such cases the use of a vacuum tanker is impracticable.

The dumping stations for the vacuum tanker contents are in sewer manholes near the sea outfall. The problems associated with such dumping are (i) silting up the sewer (ii) floating solids which may get swept upstream and deposited on shores are highly undesirable (iii) odour nuisance.

1.3.0 IDEALIZED PIT LATRINE COMPOSITION

Pit latrine contents vary in material composition from one pit to the other depending on the types of non-excreta waste thrown therein as ablution material or domestic waste disposal, thus throughout the report, a generalized case will be considered.

The pit contents could also be categorized as wet or dry, the wetness being attributed to water used for anal cleaning; shower water discharged

into the latrine instead of soakaway or open drains, the location of pit latrine, i.e. if it is in a high groundwater table or flooding areas during the rainy seasons.

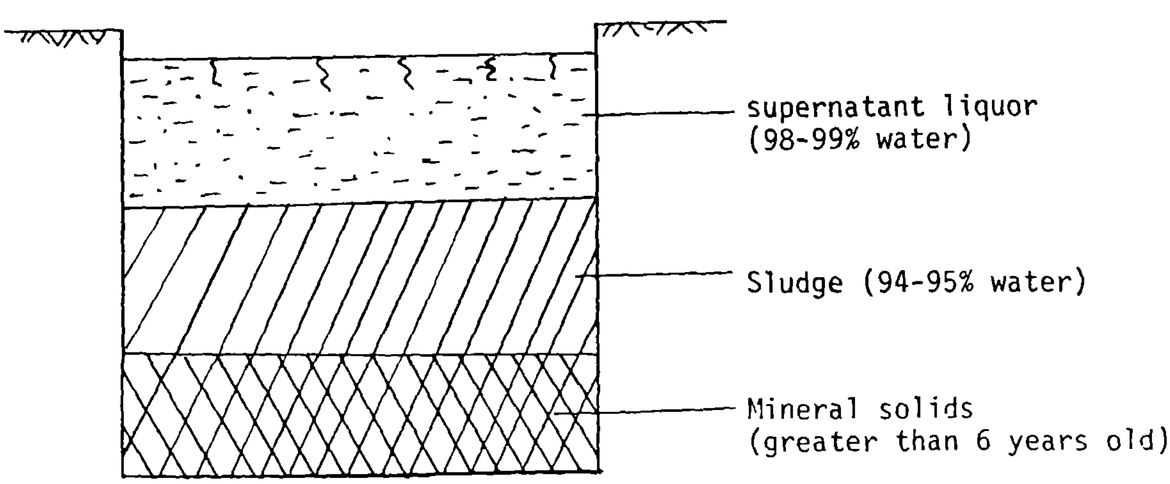
The study carried out in Dar-es-salaam by the Ministry of Land, Housing and Urban Development in 1979 indicated that during the rainy season 60% of the latrines suffered from excreta rising in pits; over 98% of the latrine users use water for anal cleansing and 45% of pit latrines were between 6-20 years old.

The age of the pit accounts for the three idealized phases which are thought to exist in old latrines.

The top layer is mainly supernatant liquor containing 98-99% water, the middle layer is a sludge containing about 94-95% water, 5-6% solids and the bottom one is thought to be a hard pan of sludge (mineral solids) which is formed by settlement and consolidation of excreta and other materials as time between emptying is rather long (5-15 years).

The three phases could be depicted diagramatically as shown in Figure 3.

Figure 3



In some areas where the ground water level is very low and water is not customarily used for anal cleansing, the pit contents are relatively dry, thus the supernatant liquor layer may be absent.

1.4.1 QUANTITY AND COMPOSITION OF HUMAN FAECES AND URINE

In order to determine the desludging rate of pit latrine with given volumes, the quantity of nightsoil accumulation should be known or approximated.

From surveys carried out in different areas, it has been established that the average excreta production is of the order of 1.0-1.1 litres per person per day.

Also the quantity by weight, physical and chemical composition are of interest in defining different emptying and treatment processes. Table 1 shows these variables.

TABLE 1. QUANTITY AND COMPOSITION OF HUMAN FAECES AND URINE

	Faeces	Urine
Approximate Quantity		
Moisture weight per person per day	135-270 g	1.0 - 1.31 g
Dry solids weight per person per day	35-70g	50 - 70 g
Approximate Composition (%)		
Moisture	66-80	93 - 96
Organic matter	88-97	65 - 85
Nitrogen (N)	5.0-7.0	15 - 19
Phosphorus (P)	1.3-2.4	1.08- 2.16
Pottasium (K)	0.83-2.1	2.6 - 3.6
Carbon	44-55	11 - 17
Calcium (Ca)	2.9 - 3.6	3.3 - 4.3
C/N ratio	5.0 - 10	0.6 - 1.1

From: Gotaas, H.B. Composting - Sanitary Disposal and Reclamation of Organic Wastes WHO 1956

1.4.2 OTHER NIGHTSOIL PROPERTIES

An average of analyses of samples of nightsoil collected in Japan revealed the following results as shown in Table 2.

TABLE 2: NIGHTSOIL PROPERTIES

PH	8.5
Total solids	30.1 g/l
Suspended solids	12.0 g/l
Volatile solids	17.6 g/l
Ash	12.5 g/l
BOD	10190 ppm
Ammonia Nitrogen	3471 ppm
Chloride Ion (Cl^-)	4671 ppm

From: Prandt, L.A., Water Research Vol. 5

[illegible]

CHAPTER 2

2.0 RECENT DEVELOPMENTS IN EMPTYING, TREATMENT AND DISPOSAL

2.1.0 EMPTYING VEHICLES

2.1.1 HISTORY

Vacuum trucks which offer possibilities for excreta removal from ground tanks with minimum health risks of contamination of the environment during operation are known to have been introduced in Germany before 1880, they operated both manually and automatically. Figure 4.

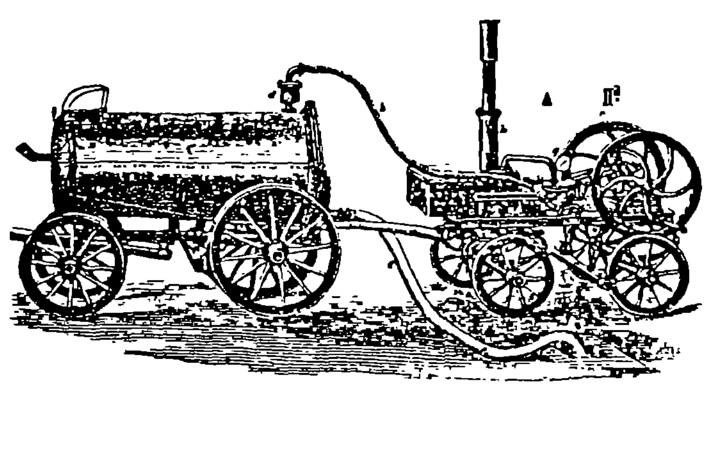


FIGURE 4: Type of Vacuum Truck used in Germany before 1880 (C.F. Hilden, E., Müller, A)

2.1.2 PRESENT DESIGNS AND FIELD TRIALS

Ever since there have been modifications of such designs, today, the system of excreta removal from specially designed vaults using a modern version of the trucks on a two to three weeks basis is practiced in big cities of Japan, Taiwan and Korea.

The vacuum trucks available in most developing coutries are specifically designed for emptying cesspools not pit latrines. That is why so may problems are encountered when attempts are made to use them in such a field.

In the U.S.A. some designs have been developed and field trials undertaken using simulated pit latrine contents with varying ranges of moisture contents.

The two types of emptying vehicles were tested by world bank staff. The types are:-

(1) High airflow type which functions on principles similar to that of vacuum floor cleaners in which a very large volume of air is drawn through a pipe which is kept just above the surface of the material to be removed.

The material is caught up in the airstream and deposited in a hopper on the unit.

(2) Vacuum tanker type working on principles of evacuating air from the tank thus creating a negative pressure therein. By operating an appropriate valve and dipping the suction pipe into the sludge (or any other material) suction into the tank is effected.

Both types of equipment functioned well to some extent with wet materials* with dry ones, some water had to be added to attain the same performance.

* The vacuum type's performance was higher than that of air lift one.

From operation point of view, of the two types type (a) requires skill and more manpower (at least three men) more than type (b) which requires only two crew.

The selection of the type to be used or modified depends very much on the equipment common in the country; capital, operation and maintenance costs, level of sophistication and ease of procurement of spare parts for repairs.

Of the two types; alternative (b) qualifies for consideration for modification so as to be used effectively in developing countries until such a time as an optimum design and the advantages of type (a) overide those of type (b).

2.2.0 TREATMENT AND DISPOSAL

Whether nightsoil is collected by buckets, carts or vacuum trucks, it must be disposed of hygienically in order to avoid health hazards associated with traditional methods.

These traditional techniques have been practiced in some Asian countries. They include, spreading excreta on farms, feeding fish ponds, composting and trenching.

In some parts of the continent, countries with developed economy use very advanced methods for treatment and disposal viz. (i) chemical treatment, (ii) treatment at special plants (iii) aerobic treatment and anaerobic digestion.

Waste stabilisation ponds have operated on an experimental basis for a limited period in South Africa.

These techniques are discussed in detail. The order does not reflect preference or least cost alternative.

2.2.1 PASTEURIZATION

In Taiwan and Korea where nightsoil is used for agriculture and fish farming, a new technique has been developed for elimination of health hazards when handling nightsoil in farms.

This is pasteurization by steam injection into the waste material in order to bring its temperature up to 80^{o}C for 30 minutes.

Some research on steam injection into the nightsoil has demonstrated that ascaris eggs are destroyed by 60^{o}C/20 minute pasteurization.

Higher temperatures are required for amoebic cysts and virus.

After this treatment the wastes may be used safely in vegetable or fish farms.

The advantage of the process is that it utilizes known technologies such as steam generation and equipment that can be locally manufactures by light industries.

2.2.2 TRENCHING

The trenches are usually dug one metre wide and deep, filled with excreta to within 200-300 mm of the top and then covered.

This may be a least satisfactory and offensive method if not properly located and supervised, as it may expose the fresh excreta to fly breeding; there can be smells and unsightliness nuisance; in some areas surface runoff from the disposal sites may lead to water pollution.

It could be a short term satisfactory method if all these factors are observed and precautionary measures taken.

2.2.3 WASTE STABILIZATION PONDS

Experience has shown that in conventional sewage treatment systems, this is an efficient method in destroying pathogenic bacteria and the ova of intestinal parasites.

Although stabilization ponds have traditionally been used for the treatment of water borne sewage, there is no reason why they could not be used also for the treatment of nightsoil collected by vacuum trucks or otherwise. Experimental work carried out in South Africa for 13 months on this aspect reveal ed promising results.

The size of the pond and set up of other associated features are shown in Figure 5.

SPECIAL FEATURES OF THE SYSTEM

(a) A mixing tank for receivingexcreta is situated on a ramp. Water from the pond is pumped into it in order to sluice the nightsoil so dumped and ensured that all residue is washed into the pond and sufficiently dispersed so that sludge banks are not formed at the pond inlet.

(b) There is provision of a pump which draws water from the pond for diluting and washing down the sludge and breaking up floating solids.

The water content in nightsoil is too low relative to putrescible matter as compared to that of raw sewage.

Thus in order to apply the same pond loading in the case of nightsoil as that of raw sewage; water was added to make-up for evaporation and seepage losses thus keeping the pond full.

The system being a "closed" type (no effluent from the pond) led to progressive increase in dissolved solids concentration in the pond, thus

affecting the properties of the content and performance.

POND LOADING

The loading of approximately 3000 persons per hectare under South African climate conditions was applied.

Alternatively the area of the pond could be obtained by applying the design loading equation.

$$\lambda s = 20T - 120$$

where λs = design loading kg/ha.d

T = Temperature in ^{o}C

Approximately the BOD_5 production per person per day and knowing the temperature and design population the ponds could be easily sized.

POND PERFORMANCE

The bacteriological quality of pond contents was comparable with that of a primary raw sewage pond at the same loading.

There were no odours or fly nuisance from the pond itself, but these could be detected shortly after dumping of nightsoil.

Algae were always present to a lesser or greater extend indicated by a green colouration of the pond.

Prototype ponds designed on pilot scale could be constructed with a provision of several dumping points around the pond but a long term performance could not be guaranteed as the experiment lasted for 13 months only. Hence, not much could be concluded with certainty.

Two main drawbacks with this method would be:-

(a) An adequate water supply should be ensured to make up for losses, but water is a scarce resource in some parts of developing countries and thus guarantee of its adequacy is doubtful.

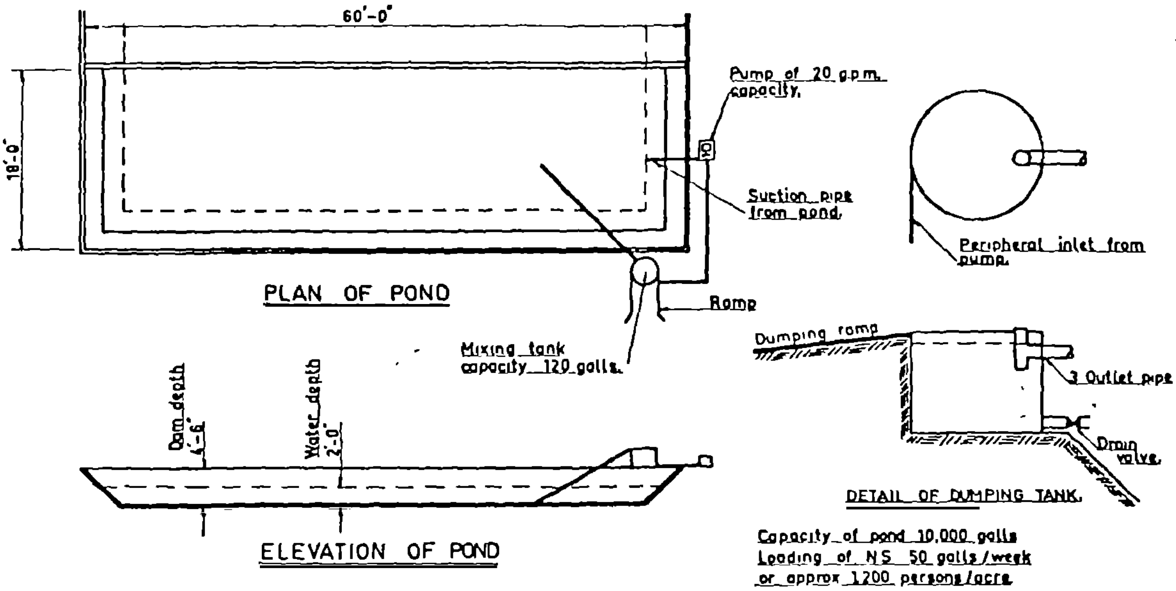


Fig 5. Details of Pilot Scale Pond for Nightsoil Treatment.

Waste Stabilization Pond - South Africa (From: Public Health Johannesburg (S.A.) Vol. 63. by Shaw, V.A.)

(b) Provision of circulating pumps: These will increase the capital, operation and maintenance costs of the whole system. Mechanical breakdowns of the pumps or prolonged power cuts will adversely affect the operation performance.

2.2.4 TREATMENT AT SPECIAL PLANTS

In Lagos-Nigeria, a special plant for nightsoil treatment was built in 1973; consisting of two aerated lagoons (each 55 m square, 3 m deep and having four 75 h.p. aerators), recirculation pump, screening, macerating house and power supply controlling units.

The total volume of nightsoil collected and received at the plant is $180 m^3$/day with total BOD_5 load of 8300 kg/day.

After the nightsoil has been screened to remove large debris, it is diluted in a mixing chamber with water from Lagos lagoons and recirculated mixed liquor. It is further macerated and from thence treated in aeration lagoons which operate on the conventionally-loaded activated sludge process. The effluent is discharged into Lagos lagoons without further treatment.

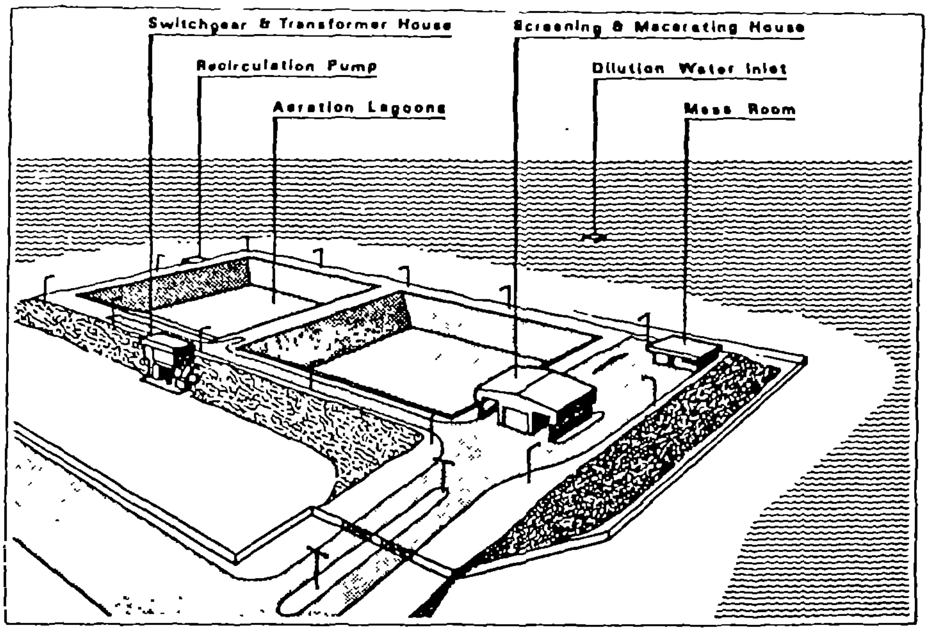


Fig 6. Night soil treatment plant - Lagos Nigeria.
(From Hindhaugh, G.M.A. The Consulting Engineer (9))

The process has a capability for future treatment of water borne sewage with minimum modifications. The disadvantages of the process are:

i) It requires high capital, operation and maintenance costs.

ii) It needs a reliable power supply.

iii) It should be constructed in a location where adequate dilution water can be obtained and near the sea for final effluent discharging.

iv) The level of its sophistication is high relative to the skill of manpower locally found in developing countries.

2.2.5. ANAEROBIC DIGESTION

The process has been practiced and developed in China, Korea and India for the last 20-30 years. Apart from offering satisfactory treatment of the excreta, the process has an advantage of producing fuel in the form of gas as a source of energy and digested sludge used as a fertilizer.

Digestion of nightsoil alone has shown a low volume of gas production (depending on dietary habits). Thus in India human wastes are mixed together with animal wastes (cow dung and piggery wastes).

The total energy production would double the amount produced from conventional power stations for the same investment.

Advantages of digesting both animal and human wastes together are:

1) Risks of enteric diseases are reduced.

2) The use of digested sludge as fertilizer; the improved fertilizer value would reduce the need for imported and expensive organic type.

3) It helps to remove foul smells and to reduce the breeding of houseflies.

2.2.6 CHEMICAL TREATMENT

In Japan, various advanced treatments are applied. One of them is the chemical process in which the nightsoil is first screened, then treated with lime and ferrous sulphate in a clariflocullator.

Since about 60% of the night soil solids are in solution, the main purpose of chemical addition is to precipitate and coagulate the solubilized solids rather than primarily to make the night soil filterable.

The supernatant liquor is diluted at least 20 times with fresh water and treated aerobically in the same way as conventional sewage treatment.

The sludge produced is dewatered by filter, sand bed etc., and disposed of by incineration. A flow diagram of a typical treatment plant is shown in figure 7.

A chemical treatment plant has problems with odour and short life of equipment which is usually made of carbon steel. It costs less to install but more to operate comparative to other advanced treatment processes. The process itself is trouble free due to its being independent of biological action.

Fig 7.

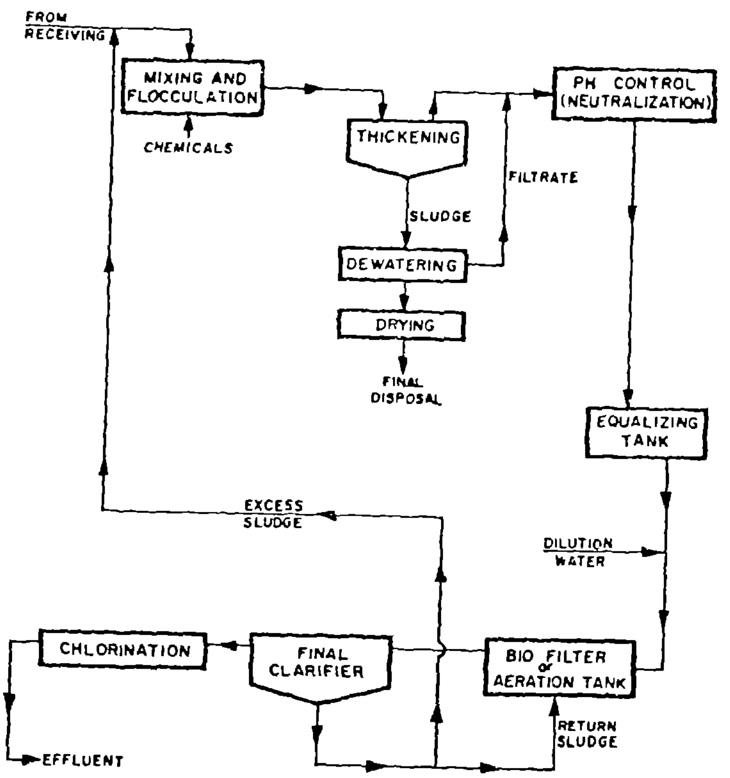


FIG. 7. Night soil chemical treatment process.

2.2.7. COMPOSTING

The composting of nightsoil in a systematic way was introduced in China in 1930. This practice is still an important component of rural health programs. In many parts of the world night soil is composted alongside with town refuse.

This could be satisfactorily used for hygenic disposal of human excreta provided the operations are carried out under controlled supervision, ensuring that compost pits are properly made up and fully ripe before the material is taken out to be used as manure.

Results of research work carried out in India showed that the number and viability of helminthic ova such as ascaris and hookworm decrease rapidly within the first month and they are completely eliminated in the course of three months, due to the high temperatures (40-60^{o}c) developed and maintained in pits for a long time.

Detailed research work on the development of such treatment processes are presently carried out in different parts of the world and proposals in favour of the system being widely introduced in developing countries are put forward due to its efficiency, inexpensiveness and non-requirement of highly skilled manpower for its operation.

CHAPTER 3.

3.0 THE STUDY AND PROPOSALS FOR MODIFICATION OF VACUUM TANKER EMPTYING SYSTEM

A range of modifications and field tests of vacuum emptiers have been tried in different parts of the world, yet up to the time of this report, none of these modified versions is known to have successfully emptied simulated or actual pit latrine contents, (especially old pits).

The compacted sludge layer at the bottom of the pit and high consistency of contents in subsequent layers are responsible for rendering effective pit emptying difficult. Some techniques are suggested in this section which may be applied to alleviate these problems.

Detailed physical properties of sludge (pit latrine contents in general) are discussed so as to establish criteria which, with other factors relative to the pit latrine location and usage, will enable the determination of an appropriate device for the emptying process.

The field data used in this study were collected from Dar-es-Salaam, Tanzania and Gaborone, Botswana[7].

3.1.0 PHYSICAL PROPERTIES OF PIT CONTENTS.

3.1.1. General nature of contents.

The study showed that, 54% of the total number of pit latrines surveyed in both areas, did not reveal any rubbish in them. The common articles in the rest of the pits were rags, wood, sacks and papers.

These materials are likely to cause blockages in vacuum truck hoses but are relatively easy to remove.

The other major components are water and sludge. The scum layer at the top found in some pits where water is used for anal cleaning is normally soft and easily removed by vacuum tankers.

3.1.2 DENSITY.

Densities of representative sludge samples were determined by applying crude field methods to a reasonable accuracy. The average density was found to be 1400 kg/m^3. Samples from pit latrines in Dar-es-Salaam revealed high values (greater than 1500 kg/m^3 which is the density of organic matters - the value suggested by water research) due to the high proportion of sand content 43% (density of sand - 2650 kg/m^3).

Sludge density is important in relation to the calculation of flow, it enables the determination of maximum head through which the sludge could be sucked by the vacuum tanker from the pit.

3.1.3. MOISTURE CONTENT

The moisture content of the sludge was found to be low (average 46%). Although water is used for anal cleaning and bath water is normally drained into the latrines, the ground water level in the area surveyed was very low and the type of soil is sandy, thus leading to high permeability of water entering pits. Generally the moisture content of sludge in most pits is higher than the average obtained in this study due to the fact that the ground water level in many parts of Dar-es-Salaam is high.

3.1.4 SLUDGE COMPACTION

The compaction is brought about by (i) the overlaying layers of supernatant liquor (ii) leaching of water through the pit walls.

The rate of compaction is expected to be higher in pits situated in well drained soils and those with higher number of users (due to a high rate of sludge accumulation).

Field studies have revealed that the compaction of sludge could be related to its yield stresses obtained by the use of rotational instruments and fitting the results into mathematical models. The yield stresses of sludge have been found to vary linearly with the sludge age and increase considerably in the early period [27]. Figure 21. shows this relationship.

It was further learnt from the studies that compaction in pit latrines occurs rapidly in the first 1-3 years which means that pit contents which are older than 3 years will be difficult to desludge. This implies that the design of the pit capacity should be based on a 3 year emptying cycle so as to do away with the hard sludge layer which develops in pits older than 3 years.

The calculations for the proposed size of pit latrines are shown in appendix 6.

3.1.5. RHEOLOGICAL PROPERTIES OF SLUDGE

The knowledge of the flow characteristics of the sludge (viscosity) is critical in determination of its pumpability and means of improving this property in the general assessment of suitable equipment for this purpose.

THEORY

The sludge has the properties of non-Newtonian liquids due to its large bulky molecules and colloid structural nature. A finite stress is often needed to break down the structure and initiate flow. This stress is more critical than overcoming viscous resistance at positive flow rate.

Due to this nature, the sludge could be categorized as a Bingham fluid. Fig 8 (a) shows a Bingham fluid characteristic in which a fluid behaves as an elastic solid up to the yield stress (τ_0). Above the yield stress, the rate of shear is directly proportional to the shear stress minus the yield stress.

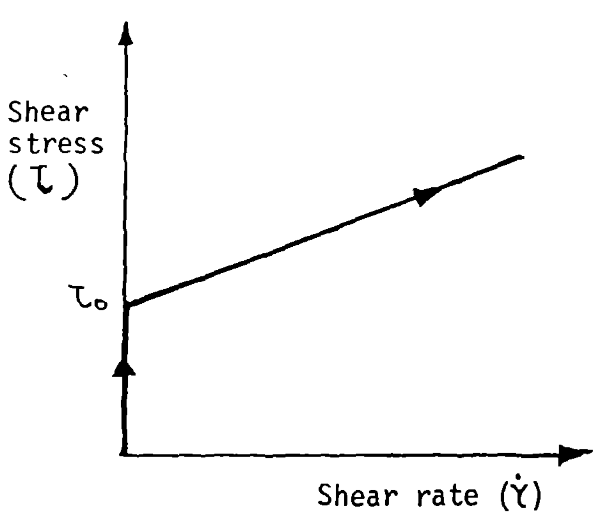


Fig 8 (a) Bingham fluid flow-curve

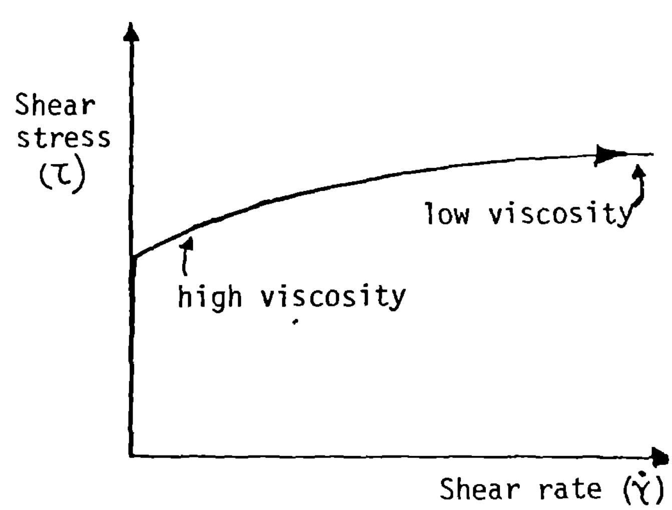


Fig 8 (b) Bingham fluid showing thixotropy.

In many cases once flow starts, the molecules tend to orient along the direction of shear. The interaction of the molecules is reduced and the viscosity diminishes as the rate of shear increases (shear thinning) See Fig 8 (b).

Also the viscosity would tend to decrease with time under the conditions of constant shear. This property of the fluid is known as thixotropy. The sludge has shown this behaviour.

(i) MEASUREMENT OF SLUDGE VISCOSITY AND OTHER PARAMETERS

So far the field studies known to the author to have been carried out in measurements of sludge properties have been made by using a rotary viscometer; which determines the torque on a rotating concentric cylinder immersed in the sample at various rotational speeds then the readings are transformed into stress/strain rate data using various models.

Use of such a viscometer can cause large errors because of problems arising due to the nature of the sludge.

The main problems encountered with the concentric cylinder type are:-

(i) Particles are often of the same order of magnitude as the annulus of the apparatus resulting in the destruction of flocs/particles during the experiment.

(ii) Formation of less dense layers next to the surface of the measuring bodies.

(iii) A tendency for the sludge to become inhomogeneous because of settling and particle interaction and thus segregation of water from sludge.

Instead of a concentric cylinder, a standard 6-blade turbine or other type of impeller is suggested to be used in sludge properties determination. The impeller type has an advantage that it achieves mixing and no water layer is developed adjacent to the stirrer blades.

(iii) SETTING OF MEASURING EQUIPMENT.

In order to measure the torque on the impeller of the viscometer system, the equipment shown in Fig 9 (a) is used. This rotational viscometer consists of a measuring head connected to a control panel, an impeller and a glass beaker in which a sample is placed. The dimensions of an impeller used in such studies are also shown in Fig 9 (b).

Constant temperature precautions are not necessary because the viscosity of this kind of suspension is only slightly dependent on temperature. The experimental results enable the determination of the flow curves and other consistency parameters.

EVALUATION OF EXPERIMENTAL DATA.

The values of torque on impeller measured at various rotational speeds could be fitted into some mathematical models such as:-

i) Power Law: $\tau = k^{\ n}$ where τ = shear stress, τ_o = yield stress

ii) Bingham model: $\tau = \tau_o + k\dot{\gamma}$ $\dot{\gamma}$ = shear rate

k = consistency index

n = flow index

and other models, in obtaining the relationships between sludge properties.

The use of the Impeller viscometer system is based upon the principle that: The power consumption of an impeller can be expressed as :-

$$P = Po\rho N^3 D_r^5 \quad \ldots \quad (1)$$

where P = power comsumption (w)

Po = Power number ( )

ρ = density of fluid (kg/m^3)

N = impeller speed (S^{-1})

Dr = impeller diameter (m)

In the laminar flow regime ($Re<10$) the power number of an impeller is given by

$$Po = \frac{C}{Re} \quad \ldots \quad (2)$$

Wher c = constant (-) depending on impeller dimensions for a non-Newtonian fluid theReynolds number can be written thus

$$Re = \rho \frac{ND_r^2}{\eta a} \quad \ldots \quad (3)$$

where ηa = apparent viscosity (NSm^{-2})

The power consumption can be related to the torque on the impeller

$$P \cong 2\pi N M \quad \ldots \quad (4)$$

where M = torque (Nm)

Combining equation (1), (2), (3), and (4) gives a relation between torque and impeller speed in form:-

$$M = \frac{C \eta a \, NDr^3}{2\pi} \quad \ldots \quad (5)$$

So by measuring the moment M as a function of the impeller speed N for a Newtonian liquid (ηa = constant), the constant C can be determined.

The average shear rate around the impeller in the laminar flow regime as expressed by Calderbank and Moo-Young (1959) is:

$$\dot{\gamma}av = k.N \quad \ldots \quad (6)$$

where k is a constant(about 10)

The above relation is independent of the rheological characteristics of the fluid, but is dependent on the measuring system used.

The shear stress can be written:

$$\tau = \eta a \cdot \dot{\gamma} av \quad \ldots \quad (7)$$

for the liquid that follows the power law

$$\tau = k\gamma^{n} \quad \ldots \quad (8)$$

Combining equations (6), (7), and (8) gives

$$\frac{\tau}{\dot{\gamma}} = \eta a = k\dot{\gamma}^{n-1} = K(Nk)^{n-1} \quad .. \quad (9)$$

For a given non-Newtonian power law liquid of known rheological behaviour, (k and n are determined by concentric cylinder viscometer and using a power law), η_a can be calculated from equation (5) and when the moment M is measured as a function of the impeller speed N, then k can be found from equation (9).

Equations (5), (6), and (7) result in

$$\tau = \frac{2\pi Mk}{CDr^{3}} \quad \ldots \quad (10)$$

Since the constants C and k are now known, τav can be calculated using equation (6) and using equation (10).

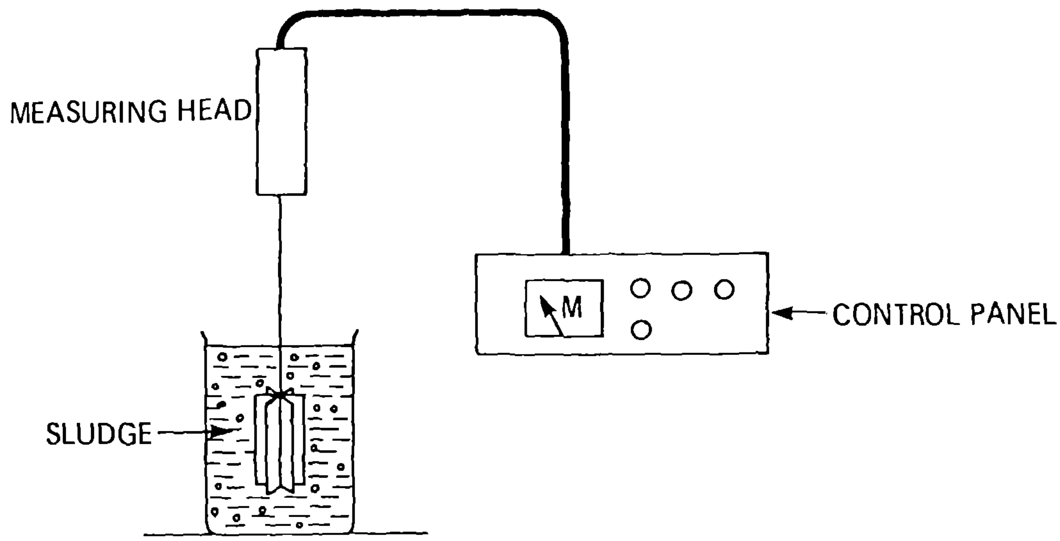


FIGURE 9(a) IMPELLER VISCOMETER

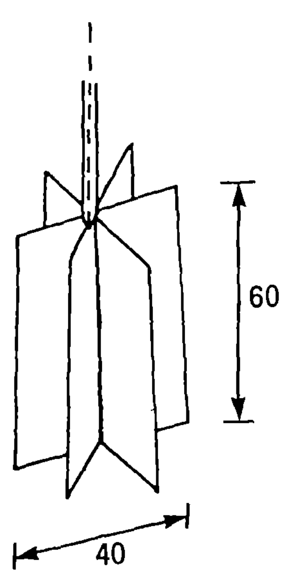


FIGURE 9(b) IMPELLER DIMENSIONS (MILLIMETERS)

NOTE In concentric cylinder viscometer $\tau = \frac{M}{4\pi L}\left(\frac{1}{R_1^2} + \frac{1}{R_2^2}\right)$ and $\dot{\gamma} = \Omega\left(\frac{R_2^2 + R_1^2}{R_2^2 - R_1^2}\right)$

R_1 & R_2 are radii of inner and outer cylinder, L = their length and Ω = angular rotation velocity.

The yield stress corresponds to the torque applied on the impeller when it starts to rotate.

With the setting of the equipment as previously described the variation of sludge properties with various factors could further be determined.

RATE OF SLUDGE FLOW [27]

The flow of sludge in a pipe could be determined by using a mathematical model combining the consistency parameters n and k as shown in equation (11).

$$Q = \frac{\pi R^2 n}{3n+1} \cdot \left(\frac{P'}{2k}\right)^{1/n} \cdot R^{1/n} \quad \ldots\ldots \quad (11)$$

where R = the pipe radius (m)

P′ = the pressure gradient (pressure less in overcoming the friction per unit length of a pipe (N/m^2)

Q = sludge flow (m^3/s)

Different sets of parameters n and k could be obtained from samples with varying moisture contents.

Field experience has shown that a small increase in moisture content of sludge associated with effective mixing results in high sludge flow values[7].

The maximum yield stress allowing flow of sludge can be determined from

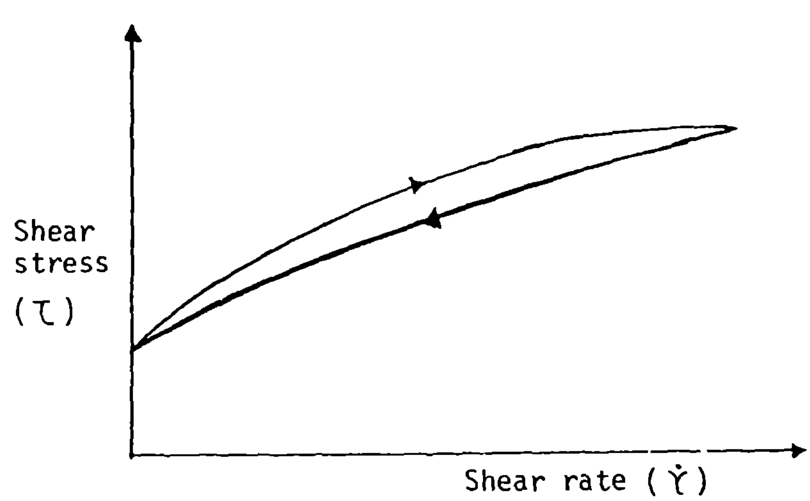
$$\tau_o = \frac{P'R}{2} \quad \ldots\ldots \quad (12)$$

3.1.6 HYSTERESIS EFFECT OF SLUDGE.

Field work has shown that the sludge, like other thixotropic fluids, will almost recover its original viscosity if allowed to stand for a sufficient length of time after it has been agitated and its viscosity decreased.

The plot of shear stress (τ) against shear rate shows a hysteresis effect when the shear rate ($\dot{\gamma}$) is changed at regular intervals. The curve obtained for increasing shear rates does not coincide with that for decreasing rate. See Fig. 10 below:

FIG. 10. Hysteresis effect of sludge.



The time mentioned on the previous page is yet to be determined, the knowledge of which will enable the estimation of the maximum period between emptying to prevent sludge caking in the vehicle's tank.

3.2.0. OTHER RELEVANT FACTORS.

3.2.1. ACCUMULATION RATE OF EXCRETA IN LATRINES.

The rate of accumulation was estimated from the volume of the excreta in pits, the number of users and the age of the sludge (the period since the pits have been put into use or since last emptied for old ones).

In Dar-es-Salaam and Gaborone, 70% of the pits surveyed showed an evenly spread distribution of accumulation between 9 and 56 litres per person per annum (lpa) with a mean of 30 lpa.

Pits concerned are mostly perennially or seasonally wet, thus it is suggested that the commonly accepted design value of 40 lpa for wet pits be reduced to 30 lpa (0.03 m^3/person/year).

The distribution is shown in figure 20.

3.2.2. ACCESSIBILITY.

The two aspects to consider regarding this factor are:

1)Accessibility from the roadway to the pit structure.
2) Access into the pit itself.

In Dar-es-Salaam the buildings are generally densely packed with poor access particularly in high density squatter areas.

Most of the distances are in the range 20-40 meters which is typical of plot width in planned areas.

Figure 11 shows the plot size of a typical Swahili house and the location of the pit latrine in relation to the house and other household facilities.

In certain densely packed unplanned areas, in which one or more plots are between latrine and the nearest roadway, distances above 60 meters are common. Distances greater than 60 meters are not likely to occur due to the limitation by the squatter upgrading policy. Figure 19. shows the distances Access into the pit itself is through a rectangular squatting hole with minimum dimensions of 150 mm x 120 mm.

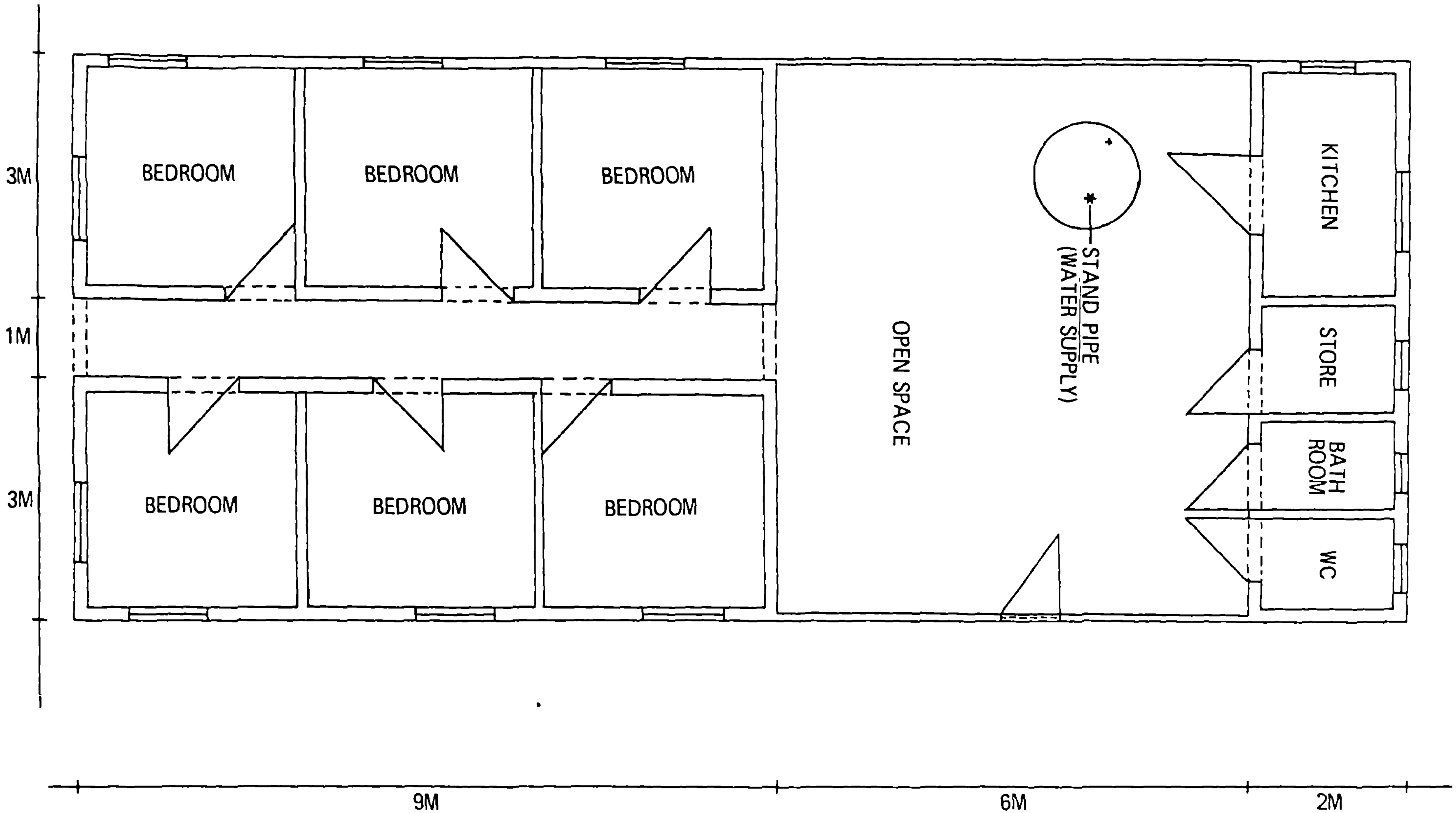


Figure 11. A TYPICAL SWAHILI HOUSE PLAN

3.3.0 VACUUM TANKER MECHANISM.

The tanker works on the principle that air is trapped from a tank by an exhauster pump (usually of a sliding vane type which comprises a slotted rotor mounted asymmetrically in a substantially circular casing with rigid blades fitted in the rotor slots which are free to slide radially). See fig 12 below for illustration.

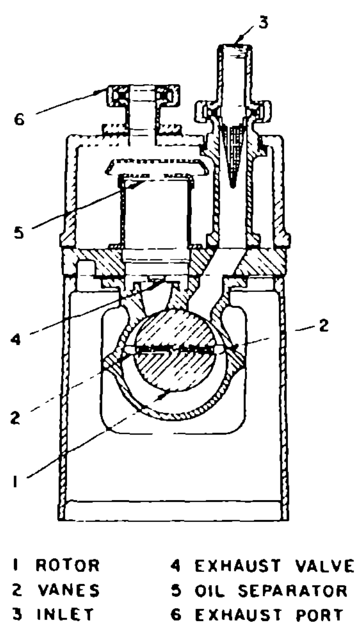


Figure 12. Sliding vane mechanical pump

From: A handbook of high vacuum Engineering.

The pump is installed upstream of the tank and therefore does not handle the waste material. It is driven by a power take off (PTO) from the vehicle engine(gearbox). With a valve in the hose line closed, a negative pressure (below atmospheric) is created in the tank.

The air so trapped is compressed and then discharged through an exhaust valve. The emptying hose is then fully immersed into the material to be pumped which is exposed to atmospheric pressure.

On opening the valve, the material is driven along the hose to the tank due to the pressure differential. In entering the tank the flow velocity drops due to the sudden increase in cross-sectional area from the hose to the effectively infinite cross sectional area of the tank, which results in material falling to the bottom of the tank.

With continuous extraction of air from the tank at a rate to match the limited cross sectional area of full hose or almost full of flowing material, a continuous flow along the hose can result.

The movement of material along the hose can be inhibited by the loss of vacuum in tank due to introduction of air by, for instance, attempting to draw dry material with air-filled voids. Thus air only is drawn into the tank.

Also sound suction hose and undamaged couplings are essential if vacuum is not to be lost and time wasted.

A check valve which automatically closes when the pump is not running is one device used to hold vacuum.

3.3.1. EMPTYING OPERATIONS USING VACUUM TANKERS.

Pit emptying operations in which backflushing is involved includes four main stages in the process, viz (i) setting up of equipment (ii) backflushing (ii) emptying (iv) cleaning up. In the study area stage (ii) is normally not practiced.

Setting up

It includes engaging the power take off (PTO) starting up the pump, pressurizing the tank and connecting the hose lengths.

Backflushing

This includes flooding the latrine, using a pressurised water tank, closing off the valve and switching the pump from pressure to vacuum.

Emptying.

This is the suction of the diluted pit contents utilizing the vacuum so created in tank.

Cleaning up.

Includes cleaning the end and inside of the hose, dismantling and storing the hose, disengaging the pump and the power take off.

At the treatment/disposal sites the tank contents are discharged by opening the discharge valve and pressurizing the tank.

3.3.2. PROBLEMS ENCOUNTERED IN BACKFLUSHING PROCESS.

Although backflushing is a valuable technique when applied to pits with dry wastes, in raising their moisture content to a level which is manageable by suction, it has several drawbacks, viz, (i) pit side walls are structurally weakened (eroded) if not lined (ii) pressure has to be applied in creating a water jet, and this entails extra fuel consumption (iii) the water added increases the amount of total load to be extracted and carried (iv) the tank should contain two chambers, one for clean water and the other for sludge. This reduces the sludge carrying capacity of the tanker.
(v) Field experience has shown that simple backflushing or even high pressure jetting do not break down the sludge layer at the bottom of the pit.

The agitation of the layer by some other mechanical operations is required to overcome this problem.

3.4.0 PROPOSALS FOR MODIFICATIONS

In this section some modification proposals on the present pit emptying processes using the vacuum trucks are detailed. The combination of all or some of the proposed features is expected to result in a substantial improvement of the equipment.

3.4.1. USE OF AGITATORS.

As was explained in previous sections the effective emptying of pit contents (particularly with old latrines) requires the breakdown of the hard sludge layer and thorough mixing of the contents with even small quantities of water which may often already be present in pits, so as to reduce the high viscosity and improve the pumpability.

An agitator rotated in a sludge confined in pits will accomplish this prerequisite. A rotating agitator generates high velocity streams of liquid which in turn entrain stagnant or slower moving regions of liquid resulting in uniform mixing by momentum transfer.

Agitators can be classified into two groups:

(i) Agitators with a small blade area which rotates at high speeds- Fig. 13(a)

(ii) Those with a large blade area which rotate at low speeds - Fig. (13(b)

The second group is more effective than the first in the mixing of relatively high viscosity liquids and depend on a large blade area to produce liquid movement. They are considered useful for mixing sludge. Thus a gate type anchor agitator (see Fig. 13(a)) is proposed

for this purpose in the study.

OPERATION

The mean shear rate produced by an agitator in mixing a liquid, $\dot{\gamma}m$, is proportional to the rotational speed, N.

Thus $\dot{\gamma}m = kN$

where k is a dimensionless proportionality constant for a particular system.

With such rotating agitators, the shear rate is greatest in the vicinity of its blades. In fact the shear rate decreases exponentially with distance from the agitator [25]. Thus the shear stresses and strains vary greatly throughout an agitated sludge resulting in variation of its viscosity throughout the pit. This will significantly influence the mixing process.

The aforementioned condition will only occur if an agitator is stationed at a fixed position in a pit, but the situation could greatly be improved by swirling the rotating agitator around the pit, in this way a more or less uniform sludge mixture is achieved. To facilitate this, an agitator should be connected to the vehicle power source by a flexible cable.

Power Requirement.

The power to run the agitator is supplied from the vehicle's engine through the power take off (PTO). With known sludge properties, and agitator dimensions and its rotational speed (N) at which a thorough mixing of sludge is effected, the power required could be determined from the equation $P = Po\, \rho\, N^3\, D_a^5$

Da = Agitator diameter.

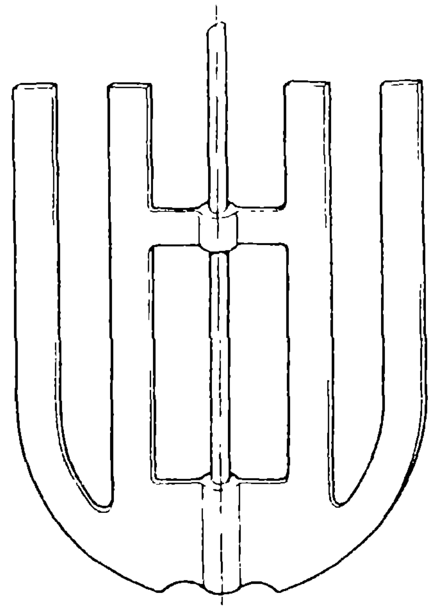


Figure 13(a) Gate type anchor agitator

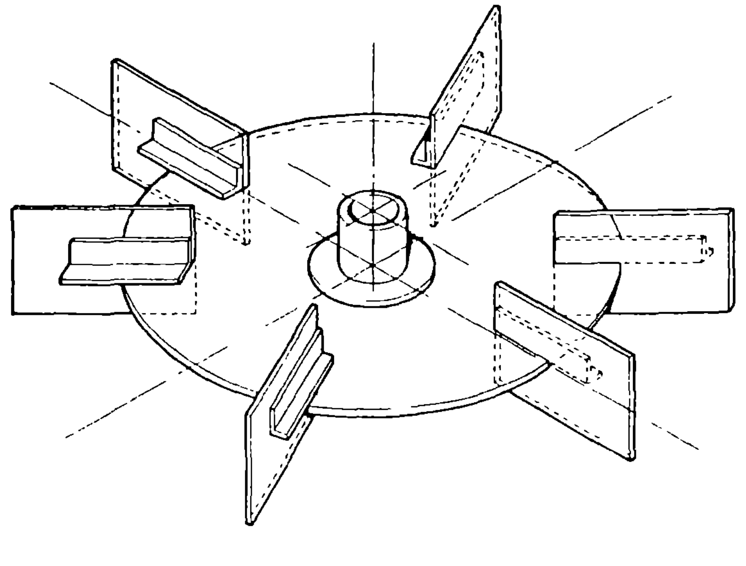


Figure 13(b) Six blade flat blade turbine

Additional power is required to overcome mechanical losses which occur in all mixing systems.

Agitator Design

The sizing of an agitator should be based on field data related to the pit latrine design and other relevant information.

3.4.2 INJECTING AIR INTO A SUCTION HOSE

Compressed air from the vacuum pump exhauster could be used to assist mixing and reduce the density of the fluid column height. The air could be conveyed from the exhaust by a Ø20 mm plastic hose and injected into the intake of the suction hose. The air flow (exhauster throughput) is in a range of 300 cu ft/min. This portion of the suction hose is to be made of steel and should be inserted vertically into the pit. It is then coupled to a normal flexible hose length.

The arrangement of the setting is shown in Figure 14.

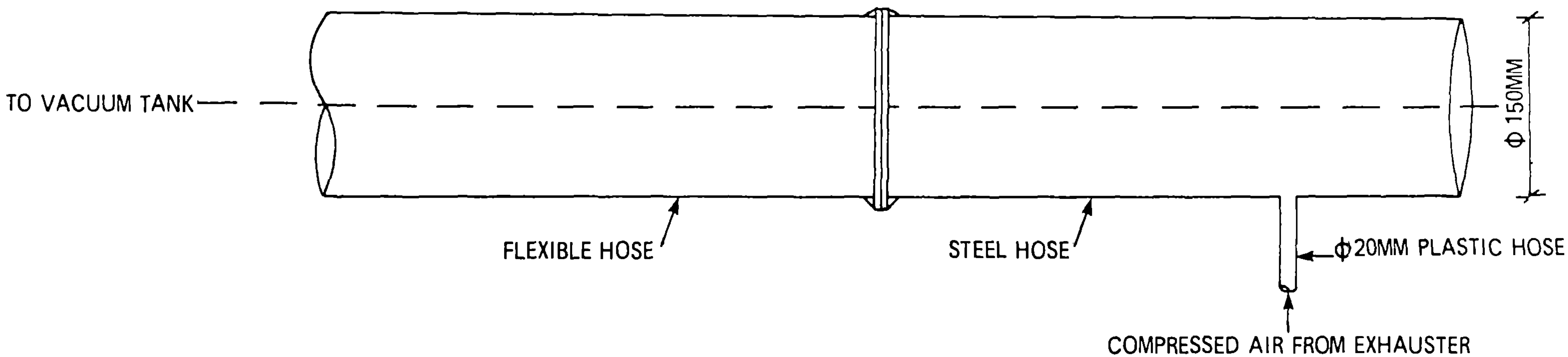


FIGURE 14. AIR INJECTION INTO A SUCTION HOSE

This method of recycling the exhaust air has an advantage that apart from accomplishing the operation, it helps in controlling the bacteria and pathogen spread into the atmosphere*.

3.4.3 THE SIZING OF A SUCTION HOSE

a) Diameter

The sizes of vacuum suction hose currently used in the study area range between 75-100 mm diameter. This range of hose sizes has been observed to suffer considerable blockage during emptying of pits.

A 150 mm diameter hose should be tested. Although this size is more expensive and heavier than the Ø100 mm, it suffers less blockages and has less frictional losses than the latter.

b) Length

The maximum length of the suction hose is determined by the power capacity of the vacuum pump.

Vehicles with the capacity to operate with suction lengths up to 76 metres are now manufactured[28]; the length is deemed adequate given the configuration of the pit latrine accessibility from the roadway in the study area.

3.4.4 INCREASING THE POWER CAPACITY

It is proposed that the pump be uprated to a 40 H.P. unit, relative to the present 18 H.P. unit, in order to create an effective vacuum in a relatively short time.

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* Results on air samples from vacuum truck exhausters have shown them to contain pathogenic organisms - in measurable amount.

\- World Bank Report by Richard Middleton

3.4.5 DISCHARGE MECHANISM

For the existing design of tankers, the discharge mechanism is associated with pressurizing a tank. This should be altered due to the fact that extra fuel is required to run the pump during the creation of pressure, and the problems of discharging sludge particles which might have settled at the bottom of tank during transportation to the treatment or disposal site.

The proposed design of tanker should therefore include a rear door made from either pressed steel or an alluminium casting, provided with stout hinges, a rubber seal and a number of clamping screws in order to avoid distortion and to retain vacuum.

On opening the rear door a tank should be tipped by hydraulic cylinders to about 50° from horizontal for gravity discharge.

3.5.0 SUMMARY OF FEATURES OF VACUUM TANKERS SUITABLE FOR PIT LATRINE EMPTYING

Preliminary guidelines on the range of features which are most relevant to emptying pit latrines are listed below.

(1)	Inlet hose diamter	50-150 mm
(2)	Horizontal length of hose	up to 76 metres
(3)	Exhauster throughput (air movement)	$8.4m^3$/min (300 cubic foot per min) with a capability of 95% full vacuum
(4)	Vacuum rating	0.6 to 0.85 bars
(5)	P.T.O. requirement	8 to 40 h.p.
(6)	Volume of tank	up to $22m^3$

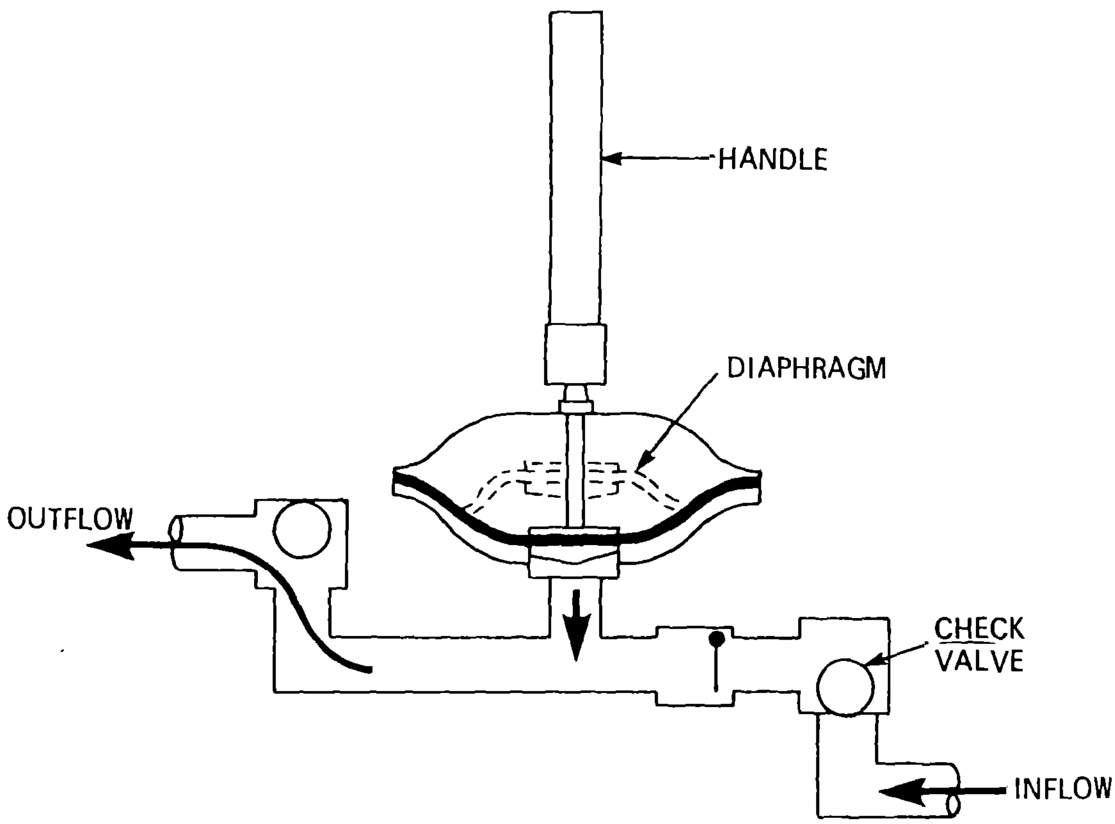


FIGURE 15 DIAPHRAGM PUMP

3.6.0 DIAPHRAGM PUMP

3.6.1 OPERATING MECHANISM

Diaphragm pumps utilize a flexible membrane that is pushed or pulled to contract or enlarge an enclosed cavity (see Figure 15). Flow is directed through this cavity by check valves which may be either ball or flap type. The capacity of a diaphragm pump is altered by changing either the length of the diaphragm stroke or the number of strokes per minute. Pump capacity can be increased and flow pulsations smoothed out by providing two pump chambers and utilizing both strokes of the diaphragm for pumping. Flexure of the diaphragm may be accomplished mechanically (push or spring) or hydraulically (air or water).

Diaphragm pumps are relatively low head and low capacity units, the largest available air operated diaphragm pump delivers 14l/s against 15 m of head.[14]

The distinct advantage of the diaphragm pumps is their simplicity, others are:-

(i) Their need for operator attention and maintenance is minimal.

(ii) There are no seals, shafts, rotors, stators or packing in contact with the fluid.

(iii) They can handle corrosive and dirty liquids with less chance of blockage or damage and much reduced wear when handling abrasive solids in suspension.

(iv) They have good suction characteristics and thus are self priming and they usually operate most satisfactorily under conditions of

suction lift.

(v) They can operate as vacuum as well as pressure pumps.

(vi) They will pump any material that will flow.

(vii) They can run in a dry condition indefinitely.

Diaphragm life is more a function of the discharge head and the total number of flexures than the abrasiveness on viscosity of the pumped fluid.

With all these features, it is believed that a diaphragm pump system with slight modifications will be able to empty pit contents effectively.

3.6.2 PROPOSALS FOR MODIFICATIONS AND OPERATION OF THE SYSTEM

The diaphragm pumps to be used in a pit emptying process could either be diesel engine or hand powered type. In each case the system should incorporate either small farm tractors and trailers or hand carts for transportation purposes.

The use of hand carts is determined by the distance of the disposal/ treatment site from the latrines. If the site is far away the transfer stations ought to be included in the collection system.

In the study area it is proposed that transfer stations should not be considered due to the likely spillage of excreta during the transfer processes resulting in fly and odour nuisance. Also this entails construction and management of such stations in each zone of emptying/ collection and thus increases capital costs of the system.

These reasons rule out the use of hand carts as the transportation method.

The device to be used for the purpose of disintegration of the sludge layer and mixing the solid particles with superinatant liquor in pits, to enable effective emptying, should be similar to that suggested in the case of vacuum tanker see Figure 13 (a) except that in this case it is to be hand operated; i.e. it is supported by a long rigid handle such that the operator turns it in a standing position conveniently.

The trailers should be locally manufactured or in some cases the bodies of written off vacuum tankers should be put in use for this purpose.

The advantages of a tractor-trailer system for collection of excreta relative to vacuum tanker type are:-

(i) Flexibility

The system would use two or more trailers per tractor. The idea of using many trailers is to reduce turn around times. When one trailer is filled, it would be brought to a dump/treatment site, unhitched from the tractor, a clean empty trailer would be hitched on the tractor and the latrine emptying task would resume while the full trailer was being emptied cleaned and prepared for further use.

(ii) Manoeuvrability

Due to its high manoeuvrability capacity the system could be used in narrow streets (-unplanned squatter areas) with little or no access problems.

(iii) Costs

The capital and operational costs are generally low.

(iv) Operational Costs

They are suitable for rough ground at disposal site and collection areas.

The disadvantage with thissystemis that the tractors are slow.

3.6.3 SOMEOF THE PUMP SPECIFICATIONS (SUITABLE FOR PUMPING SLUDGE)[26]

Hose diameter	50 mm (2in)
Delivery head	46 m (150ft)
Lift head	6 m (20ft)
Pumping rate (discharge)	1.5-2.3 l/s (20-30 gallon/min·us)

CHAPTER 4

4.0 PROPOSALS FOR NIGHTSOIL TREATMENT AND DISPOSAL

4.1.0 GENERAL ASPECTS

Objectives of nightsoil or sewage treatment are :-

1) To eliminate pathogens so as to protect human health

2) To oxidize organic matter so as to eliminate odours, nuisance and environmental problems such as algal blooms or fish kills.

Objective (1) may be achieved by separation of faeces from the community and objective (2) may be achieved by various combinations of separation, sedimentation, digestion and oxidation. Various treatment and disposal methods were discussed in Chapter 2. Some of them are not ideal for adoption in poor developing countries, while two methods are appropriate and will be discussed in detail.

They are:- Anaerobic digestion and composting.

4.2.0 ANAEROBIC DIGESTION

For making organic sludge/nightsoil innocuous before disposal, anaerobic digestion provides an efficient means in the tropics.

Some of the more important aspects of the operation are:- the control of temperature, introduction of mixing of the digester contents and PH as they all affect the growth of microorganisms responsible for digestion proce

The two important types of bacteria in the process are classified as mesophillic and thermophillic depending upon their optimum temperature range for growth.

Thermophillic (heat loving) bacteria like an optimum temperature range of 50-55°C.

Thermophillic digestion has not been quite successful in practice because thermophillic bacteria are sensitive to small temperature changes and it is difficult to maintain the required high operating temperature in a digestion tank.

The mesophillic (moderation-loving) bacteria grow best in temperature range 20-40°C, most of them thriving at human body temperature 37°C. The majority of biological-treatment systems operate in the mesophilic temperature range. Although the gas production in thermophilic digestion is more than that of mesophilic, the heat required in the former is 2.5 times that in the latter and the gas composition is essentially the same. Mesophilic digestion is common and easy to maintain thus will be considered. The biological activity variation with temperature for the two types is shown in Figure 16 below.

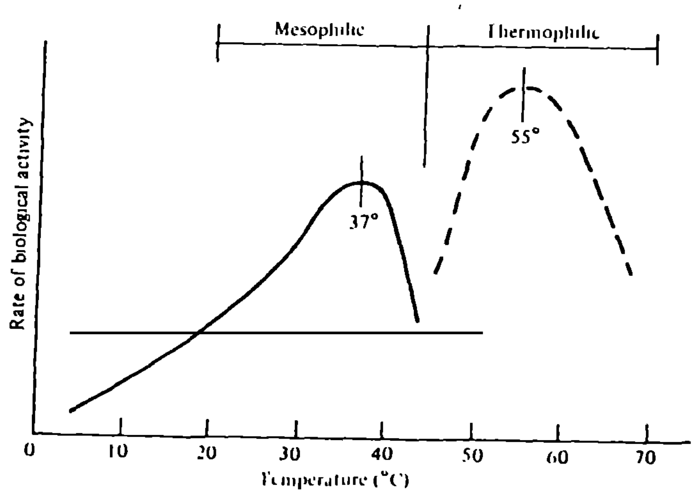


Figure 16: General effect of temperature on biological activity.[13]

4.2.1 BIOLOGICAL PROCESS OF ANAEROBIC DIGESTION

The process of anaerobic digestion is carried out by a wide variety of bacteria, which can be categorized into two main groups, acid forming bacteria and methane-forming bacteria.

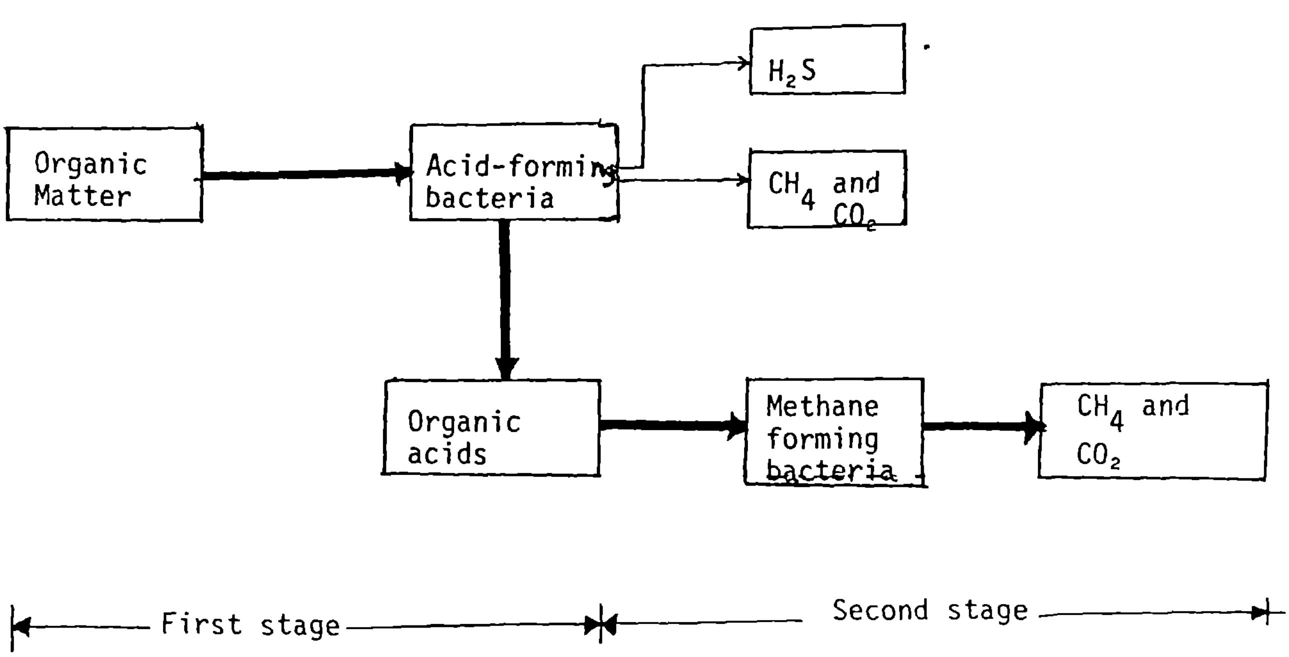
The acid formers are facultative or anaerobic bacteria which metabolize organic matter, forming organic acids as an end product, along with carbon dioxide and methane.

Methane formers split the organic acids and produce gaseous end products of carbon dioxide and methane.

Acid-splitting methane bacteria are sensitive to pH changes and other environmental conditions.

Figure 17 shows the relationship between the two bacterial stages in digestion of organic matter.

FIG 17:



4.2.2 RETENTION TIME AND TEMPERATURE

Anaerobic digestion can take place at any temperature between 5°-55°C. For normal purposes the temperature range considered is 5°-40°C. As with most biological processes, the rate of methane production virtually doubles for every 10-15°C rise in temperature and also the total amount of gas produced from a fixed weight of organic waste is considerably increased as the temperature of digestion is increased.

The optimum range has been found to be 30-35°C, as this range combines the best conditions for the growth of bacteria and for the production of methane with the shortest retention time of the waste in the digester.

The minimum retention time for the process to work is probably 2-4 days. Shorter periods are not possible because the methanogenic bacteria found in digesters have a very slow doubling rate, and also the removal of pathogems (ascaris and hookworm) will be too low.

If the retention time was shorter than this the bacteria would be washed out of the tank before they could reproduce and hence the whole process would stop.

The compromise which is usually reached is to build digesters with a retention time between 20 and 30 days.

The relationship between gas production, temperature and retention is shown in Figure 18. overleaf.

For the digesters operated in the tropics no heating is necessary in practice but mixing of digester contents is recommended to attain loading rates up to 4.5 g VS/day/l of active digester volume.

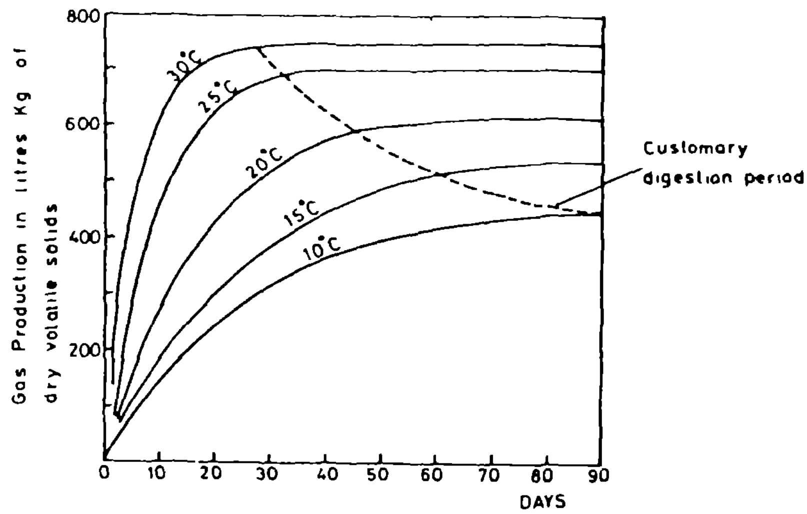


Fig 18. *Gas production at different temperatures.*[30]

With thorough mixing and addition of farm or municipal wastes which are easily biodegradable, ten days appears to be optimum, giving good gas production and a reasonable degradation of organic matter. This can only be achieved if the digester contents are maintained at a temperature of between 30-35°C.[12]

If mixing is not efficient, pockets of material at different stages of digestion, different PHs and different temperatures will occur, all of which will impair the rate of the process.

4.2.3 EFFECTS OF SOME NIGHTSOIL PROPERTIES ON DIGESTION

Nightsoil has a high PH, high concentration of ammonia, chloride, volatile solids and about 60% of the solids are in solution.[9]

It is considered that the high ammonia and or the high total dissolved solids concentrations are responsible for the inhibition of the digestion process.

The difficulties of establishing anaerobic digestion of nightsoil can be overcome by dilution with at least eight volumes of water before or after feeding the digester.

It has been shown from experimental results that continual removal of supernatant liquor maintains the digester in an active state[11]. The removed liquor can be used to dilute the incoming waste if necessary.

4.2.4 PATHOGEN REMOVAL

The work carried out in India showed that during nightsoil digestion at 37°C and with a retention time of 25 days, ascaris and hookworms were removed to the extent of 67 and 91 per cent respectively[20].

This indicates that, when properly supervised, the digested slurry could either be used on land directly or put into compost plants for further pathogen removal, in so doing assisting the compost process as will be discussed in subsequent sections.

4.2.5 LOCATION OF DIGESTERS

Depending on dietary habits, the monthly production of biogas from one person's nightsoil is around 1.0 cubic metre, whereas the monthly gas consumption for cooking would be around 4.5 cubic meters, assuming efficient burners. It implies that unless the nightsoil fed into the digesters is augmented by other materials, the digester will not produce enough gas when operated on a small scale/household basis.

It is therefore suggested that the plants be located in colleges or other places where they will collect the excreta of many people.

Even on a such large scale, it would be essential to supplement the nightsoil feed with other materials like animal and agricultural wastes (cow dung etc).

Experimental results have shown that the addition of cow dung to nightsoil digesters increased gas outout as well as helped in reducing ammonia released into the slurry[20].

The digesters should be orirtatedin the direction in which they will receive the maximum amount of sunlight to help maintain higher digestion temperature.

4.2.6 DIGESTER COMPONENTS

Digesters could be constructed using locally available materials. The two main components are the digestion tank and the gas collector. The digestion tank is usually sunk in the ground and lined with brick masonry; the gas collector (commonly circular) is made out of sheet iron 2-3 mm thick, and properly welded and sealed such that the gas leak is prevented.

Other components include the pipework, and a receiving chamber for mixing materials prior to discharge into the digestion tank. In some designs, the receiving chamber is modified by inclusion of a homogeniser which brings the solids in the night soil into a suspension before it is fed into the digester.

4.2.7 USES OF BIOGAS

The use of biogas gas evolved during the digestion process consists of approximately two thirds methane and one third carbon dioxide, and may contain 4500-6000 calories per cubic metre. One cubic metre of the gas at 6000 calories is equivalent to 2.2 kilowatt hours of electrical energy. Thus a gas could beused as a convenient source of heat at a low cost, lighting and power generation for pumping water and flour grinding.

4.3.8 SOCIAL AND ECONOMIC ASPECTS

In communities where biogas production has been practiced, there has been a resistance initially, to the use of nightsoil in household digesters. This might have been due to religious, cultural or customary beliefs.

Bearing this aspect in mind, it is suggested that initial attempts on large scale nightsoil digestion should preferably be confined to institutions like prisons, educational and health centres and other public places. This will help in standardising the technology and also in understanding possible technical and social problems to be faced in the field.

It should be remembered that the capital costs involved in installation of digesters is higher than that of say establishing compost plants; and the skill involved in the former case is quite considerable.

Considering the two methods of nightsoil treatment, composting should be preferred except in some areas where it is not feasible, in which case the anaerobic digestion could be opted for.

The prime objective of nightsoil digestion in the context of sanitation would be the improvement of hygiene rather than as a biogas unit, although certain recoverable by products such as fuel gas and manure can be obtained.

4.3.0 COMPOSTING

4.3.1 GENERAL

Composting is the aerobic thermophilic decomposition of organic solid wastes to produce relatively stable humus like material.

The principal by-products are CO_2, water and heat; none of which is objectionable. The end product, compost, is a good soil builder or conditioner containing small amounts of major plant nutrients (1.5%-2.0% N, 0.5%-1.8% P_2O_5 and 0.5%-1.0% K_2O on dry weight basis) and its fertilizing value is about the same as that of farmyard manure.

The operational advantages of this process are that it is a labour intensive and low cost technique which are some of the basic requirements for waste treatment in developing countries.[6]

4.3.2 MICROBIOLOGICAL PROCESSES

Nightsoil, refuse and miscellaneous vegetable matter which are compostable waste materials normally contain a large number of many different types of bacteria, fungi, moulds and other living organisms. Extensive studies of the microbiology of aerobic composting of organic matter have shown that a variety of microorganisms have a variety of specific functions and that no single organism, no matter how active, can compare with a mixed population in producing a rapid and satisfactory decomposition.[18]

Although many types of organisms are required for decomposition of the different materials, the necessary variety is usually present and the organisms thrive when environmental conditions are satisfactory. In aerobic composting the work is done by the combined activities of a wide succession of mixed bacterial, actinomycetic, fungal and other biological populations, each suited to a particular environment of relatively limited duration and each being most active in the decomposition of some particular type of organic matter, the activities of one group complementing those of another.

The facultativeand obligate aerobic representatives of bacteria, actinomycetes and fungi are the most active in aerobic composting.

At the start of the composting process mesophilic bacteria are characteristically predominant and later (5-10 days) the thermophilic bacteria take over and inhabit all parts of the stack or pile where the temperature is satisfactory; this is eventually most of the stack or pile.

4.3.3 REQUIREMENTS FOR COMPOSTING

Nightsoil can be composted satisfactorily alongside other municipal refuse or other organic materials such as water hyacinths (Eichhornia crassipes) so long as important requirements are observed during the process and composting operations are carried out under controlled supervision. such factors to be considered are:-

(i) Moisture Content

The proportion of moisture necessary for optimum biological activity is between 40 and 60%. Too much moisture content would adversely affect bacteriological breakdown of the compost and the amount of nightsoil (sludge) that can be added is limited by the level of the refuse moisture content[5]. If the moisture content is too low, the optimal amount may be adjusted by wetting the composting materials.

(ii) Carbon - Nitrogen Ratio

The ratio between carbon and nitrogen will determine the extent of the growth of the bacteria. Experience and experimental results have shown that the range of C/N for which satisfactory composting can be effected is 20-40 with an optimum C/N of 30 at which the rate of decomposition is most rapid[17].

(iii) Aeration

Aeration of composting material is essential for supplying oxygen to the bacteria responsible for organic breakdown.

It is accomplished by either turning the wastes in the case of pits or other confined composters or by natural/artificial airflow, through the material, in such cases where airflow facilities are provided for this purpose such as BARC system -(forced aeration). The turning of composting material does not only provide aeration but is necessary in order (a) to complete the mixing, (b) to turn the material on the outer surface, which has not been exposed to the high temperature and into which the fly larvae have migrated from the high temperature region at the centre.

(iv) Time required for composting.

The time required for satisfactory stabilization of wastes depends primarily upon (a) the initial carbon to nitrogen ratio (b) particle sizes (c) the maintenance of aerobic decomposition and (d) the moisture content.

Assuming that the moisture content is in the optimum range, that the compost is kept aerobic and that the particles of material are of such size as to be readily attacked by the organism present; all of which factors can be controlled in the composting operation; the C/N ratio determines the time required for stabilization.

This could be illustrated by an example of results of studies at the University of California in which the composting of mixed municipal refuse (garbage and rubbish) in aerobic piles with a

moisture content below 70% indicated various times for different C/N (see table 3).

TABLE 3. VARIATION OF CARBON TO NITROGEN RATIO WITH COMPOSTING TIME.

INITIAL C/N RATIO	APPROXIMATE COMPOSTING TIME REQUIRED (DAYS)
20	9 - 12
30-50	10-16
78	21

From: Composting: Sanitary Disposal and Reclamation of Organic Wastes by Gotass H.B.

Longer retention periods are required if particle sizes are large, the material is not kept aerobic or if the interior of the particles becomes anaerobic.

4.3.4. SURVIVAL OF PATHOGENS IN NIGHT SOIL COMPOSTING.

The temperature achieved depends on the oxygen content of the content of the pile, as well as the C/N ratio, the moisture content, particle size and pH. High temperatures (as those achieved in aerobic composting 50-70^{o}C) are effective in destroying pathogenic organisms.[16] Table 4 shows that all organisms of the diseases listed would be destroyed by exposure to this temperature. Pathogen-free product requirement for night soil reuse is achieved by processes incorporating long retention times.

Experimental results have shown that a retention time of 3 months is sufficient to eliminate completely helminthic ova such as ascaris lumbricoides and hookworms.[15] Turning of composting material also ensures pathogen and parasite destruction if all of the surface

material is completely turned to the inside thus exposing any organisms present to the lethal internal temperature. Also fly larvae will be destroyed before the life cycle is completed and thus fly breeding is controlled.

TABLE 4.

TEMPERATURE AND TIME OF EXPOSURE REQUIRED FOR DESTRUCTION OF SOME COMMON PATHOGENS AND PARASITES*

ORGANISM	OBSERVATIONS
Salmonella Typhosa	No growth beyond 46°C; death within 30 minutes at 55°-60°C and within 20 minutes at 60°C; destroyed in a short time in compost environment
Salmonella Sp	Death within 1 hour at 55°C and within 15-20 minutes at 60°C
Shigella Sp	Death within 1 hour at 55°C
Escherichia coli	Most die within 1 hour at 55°C and within 15-20 minutes at 60°C
Entamoeba histolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55°C
Taenia saginata	Death within a few minutes at 55°C
Trichinella spiralis larvae	Quickly killed at 55°C, instantly killed at 60°C
Brucella abortus or br suis	Death within 3 minutes at 62°-63°C and within 1 hr at 55°C
Micrococcus pyogenes var aureus	Death within 10 minutes at 50°C
Streptococcus pyogenes	Death within 10 minutes at 54°C
Mycobacterium tuberculosis var. hominis	Death within 15-20 minutes at 66°C or after momentary heating at 67°C.
Corynebacterium diptherial	Death within 45 minutes at 55°C
Necator americanus	Death within 50 minutes at 45°C
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 50°C.

*FROM: H.B. GOTAAS, "COMPOSTING" WHO MONAGRAPH SERIES NO. 31.

4.3.5. SELECTION OF COMPOSTING SITE.

The compost depot should be situated a short distance away from the outskirts of the town/city. Composting operations can be done in a town when properly conducted, but there is a possibility that errors by workmen who fail to follow proper techniques or inadequate turning will sometimes cause nuisance. Thus for aesthetic reasons it is desirable for the site to be about half a kilometre away from the town.

In selecting a site further away the additional cost of transportation of the materials should be considered.

When practicable, the compost depot should preferably be located on the side of the town opposite to that from which the prevailing winds blow.

4.3.6. COMPOSTING METHODS.

The selection of a particular composting method will depend on a number of local factors such as size of the community to be served, character of the local wastes, climate etc. There is no one standard method which could be recommended for all areas and conditions, however, the system chosen must ensure sanitary safeguards and absence of nuisance. It should also be an economic and reliable one. In the event where local climatic conditions (viz. humidity, rainfall, sunshine, air temperature and winds) may affect the composting process, modification in their effect may be made by the roofing or screening of the treatment plant. Some of the low cost composting mothods currently employed in different parts of the world are -

(i) Stack and pile

(ii) Pits.

(iii) Windrows,

(iv) BARC (Beltsville Agriculture Research Centre - U.S.A) System.

Aeration in cases (i) and (ii) is achieved by turning the materials, in cases (iii) depending on the type of construction, either turning may be required or aeration could be achieved by natural ventialtion from the interior, if a frame channel is provided across the centre of the windrow. In case (iv) aeration is achieved by mechanical means, i.e. forced aeration, using exhaust fans. Cases (i) (ii) and (iii) are likely to be adopted in the study area. Mixing of the material should be executed by labourers using long handled, long toothed rakes or ploughs for effective performance.

Manual composting must always be a primitive operation in which it is extremely difficult to estimate the proportion of the various ingredients or to limit the particle size of municipal refuse content. Thus the carbon/nitrogen content of the compost cannot be standardized.

4.3.7. SUITABLE MATERIALS FOR COMPOSTING WITH NIGHT SOIL.

The night soil is rich in nitrogen content but has a relatively low carbon content such that its C/N is too low (from tab 1, C/N range is 5-10) to suit composting requirements, i.e. C/N range of 20 - 40. Therefore some materials rich in carbon should be mixed with night soil for a successful composting process. Also the added material helps to regulate the moisture content, if that contained in the night soil collected is too high (greater than 60%).

The location of the composting plant will dictate the locally available materials to be used.

Some of the materials which are used, their advantages and

drawbacks are discussed.

(a) Municipal refuse.

In developing countries most of municipal refuse consists more of organic degradable wastes than inorganic non-degradable matter, such as metals, glass, rubber etc.

Thus, the refuse contains an appreciable carbon content, hence when composted with the night soil in proportionate amount, it will provide the required C/N and, of paramount importance, will offer hygenic disposal of both types of wastes.

It is a suitable method for urban conditions as the supply of refuse to the composting plant is guaranteed, provided the collection system is efficient. The main drawbacks with using such wasts are that, however small the amount of metals, glass etc., contained therein, sorting is necessary to separate them out. This is usually done by labourers who are exposed to health hazards, as they commonly do not wear protective clothes.

Refuse materials are composted in large particle sizes and shredding is not usually done. Thus less surface area is exposed to bacterial attack resulting in slow composting process.

(b) Tree barks.

Tree barks are piled up and left out in the open air for 6 - 8 months to remove the acids and for drying out. Then they are chopped in pieces, mixed with night soil and the composting process proceeds.

The main disadvantage using these materials, is due to the DDT

and other disinfectants which might have been sprayed on them to kill insects harmful to trees. When the disinfectant is not removed during the said period of exposure, it will affect the organisms active in the composting processes.

c) Woodchips, sawdusts, straws and rice husks.

These are excellent materials to be composted with night soil, due to their small particle size, an implication of a large surface area to be acted upon by bacteria, and thus a composting processes speeded up.

The use of these materials is subject to a constant and reliable source of supply. In some circumstances refuse is also added to balance the composting requirements.

(iv) Water hyacinths.

The water hyacinth, (Eichornia Crassipes) an aquatic plant with a rosette of leaves, is the fastest growning plant known to man, and grows favourably in a non-saline water in temperature range 26.5 - 30^{o}C. It is thus very common in tropics. It is regarded as a problem due to its ability to spread rapidly in lakes, rivers and canals. Some of the problems caused by the plants include (a) choking off drainage channels of cultivated lands, (b) navigational blockage due to the plant decay, which could possibly affect fish life, and invasion of paddy fields rendering land in some areas unproductive. By collecting these plants from the water bodies drying and shredding them, then mixing with night soil and composting, these aforesaid pollutional problems could be eliminated. The main factor to bear in mind when considering the use of these plants, is the nearness of the composting depot to the material source, otherwise

the transporting costs will not justify the economics of the composting process.

4.3.8. SOCIAL AND ECONOMIC ASPECTS.

Acceptability of using the compost.

In most African communities, compost, constituting human excrement is customarily not acceptable for use in farms producing consumable goods. In some countries such as Nigeria, propaganda and demonstration schemes have been carried out advocating its manurial value and the farmers have accepted the message to the extent that they now buy the compost from the municipal authorities for use in their farms and the demand is higher than the supply.[19]
It follows from this example that in any area where night soil composting is introduced, campaigns and demonstration schemes should be deemed an important component towards pupularizing its value.

The demonstrations could be started on Government farms producing goods not intended for human consuption. Examples are cotton, sisal, tree cultivation for beautification or for timber production. Then later the use could be extended to growth of consumable products.

ADVANTAGES OF USING COMPOST AS COMPARED WITH CHEMICAL FERTILIZERS.

The main advantages are: -The compost improves the soils water retaining capacity which is a critical factor in arid climates. Any improvement in the moisture retention quality of local soils is of vital importance to African agriculture, since rainfall in the main is ill spaced throughout the year.

- The compost when spread on farms is not easily washed away by rainfall as is the case with chemical fertilizers.

- Use of compost preserves the foreign currency which may otherwise be used for importation of chemical fertilizers. Despite the various Government subsidies, its cost is often very high when related to the income of the average peasant.

- Depending on the scale of composting (if a large one) the product could be sold to farmers, generating profits and offsetting some of the operational costs.

- If properly organized, the supply could meet the general public demand which is not a likely case with the chemical fertilizer alternative.

CHAPTER 5.

5.0. INSTITUTIONAL, ORGANIZATIONAL AND TECHNICAL ASPECTS

5.1.0. EFFECTIVE OPERATION OF THE SYSTEM.

The municipal authority should ensure the provision of an adequate fleet of trucks/tractor-trailer diaphragm pump system and skilled operatives for effective operation. Also of importance in a successful operation is the establishment of a proper maintenance system of available machinery.

The maintenance section should include well equipped workshops, skilled and experienced mechanics and a prompt spare parts procurement system. In Dar-es-Salaam there are about 30 vacuum trucks but only slightly more than half the total number are operational. This is due to improper maintenance and sparepart procurement system.

Further aspects to be considered in establishment of smooth operation of emptying, treatment and final disposal of nightsoil are detailed.

5.1.1. PROPER SUPERVISION AND OPERATIVES' WELFARE.

In most African countries particularly in the study area, nightsoil collection treatment and disposal activities are considered as a 'dirty' and low dignity type of work. Regardless of the availability of labour resource in the area, there are very few people who are willing to work in this field.

With such an attitude in peoples minds, some operatives who are employed to carry out these jobs feel unsatisfied with the official

wages they earn which are comparative to those of other low level workers employed in other different governmental or parastatal sectors. This state of affairs leads operatives, particularly working with the emptying vehicles to:

(a) Deliberately remove only half the liquor from the latrine and then the householder is told the tank is full, when they may only have a third full tanker. The householder would then have to pay extra money (unofficial) to have more liquor removed.

(b) Carry out "Unofficial" emptying, i.e. not ordered jobs.

This results into some customer orders not effected in a reasonable time; thus public faith in the service is such that many people are not prepared to waste their time putting in an order which may take up to a year to be carried out. In order to rectify and minimize these malpractices, the municipal authority should consider the following aspects:

(i) There should be instituted an organized and adequate supervision to ensure standard performance of all works.

(ii) The customer order system should be operated on a first order arrival first serve basis and carried out as soon as it is practicable.

(iii) The Authorities should ensure that suitable wage levels are maintained for skilled and unskilled labour so that it is not immediately lured away to work in private or other sectors.

In addition to wages, incentive schemes should be introduced in order to motivate the workers and make the job more attractive. These could be either semi-financial in form of meals, pensions and holidays or purely financial, the latter case is likely to be preferred by most workers.

(iii) Protective clothes should be provided to all operatives and their use during working hours ensured; also regular health checks should be carried out.

(v) A clear training program should be laid out and executed in order to update the skills of workers. The study course should be within the department and exchange with other local authorities and both onsite and in classes.

5.2.0. TRUCK COLLECTION SERVICES AND OPERATIONAL COSTS[7]

It is imperative that the municipal authority knows the full costs of operating the truck emptying services for comparison with the fees collected for these services.

The number of vehicles in an operational condition in Dar-es-Salaam average 17. Each vehicle is capable of removing about 9 loads per day each ($4.5m^3$) and is operational 6 days a week, thus totalling to an annual capacity of 48,000 loads.

This figure matches well with the estimates based on a household survey which indicated that 46,000 loads are removed annually from both septic tank soakaways and pit latrines.

An estimate of the number of loads required to service 60,000 pit latrines in Dar-es-Salaam is about 40,000 per year or an average of $3m^3$ per latrine per year.

The average demand of $3m^3$/latrine/year is likely to increase with time due to the following factors:

1) Most of the latrines are relatively new and have not yet reached a stage of becoming more or less water tight due to clogging of the surrounding soil.

2) Due to continual city growth, more houses are built in low-lying swampy areas where the high ground water table necessitates frequent emptying.

Operational costs.

The following example is for Dar-es-Salaam at 1981 prices. It is based on a fleet of 30 vehicles and is considered adequate for the city services. A discount rate of 10% has been used and lifetime of mechanical equipment estimated at 8 years, while that of civil works is estimated at 20 years. The treatment cost is not included.

TABLE 5. OPERATIONAL COSTS OF THE VACUUM TRUCK

	US $ (1981)
(A) VEHICLE COSTS.	
Capital cost,	55,000
Tax and duty	25,000
Amortization	15,000
Maintenance	8,000
Fuel (30% towntime assumed)	2,500
Labour (4 men)	4,000
Overhead (10%)	3,000
ANNUAL COST PER VEHICLE	32,500
(B) INFRASTRUCTURE COSTS.	
Building (Amortization)	100,000
Building maintenance	25,000
Vehicle workshop equipment	60,000
5 dump stations	8,000
Manpower training	65,000
ANNUAL INFRACTRUCTURE COST	258,000
ANNUAL INFRASTRUCTURE COST PER VEHICLE	8,600
TOTAL ANNUAL COST PER VEHICLE	41,000
COST PER LOAD (2,420 per year)	17

Due to the increasing costs of fuel and spare parts, the calculated costs are likely to be higher with time. At present the average charge per load is in the range of US $ 4-5.

Although the Government subsidizes the costs, it is suggested that the charge per load be increased to a reasonable amount so as to enable offsetting the operational costs.

NOTE. The private contractors (who empty pit latrines by employing local methods) would charge about US £ 50 - 75 per latrine.

5.3.0. COMMUNITY EDUCATION.

The whole sanitation program should be coupled with health education to ascertain proper and full use of the pit latrines.

As it was discussed in previous chapters, pit latrine contents in the study area were found to consist of rags, sacks, bottles and other non-biodegradable materials which were thrown in pits by the users purposely.

These materials affect the performance of the emptying vehicles whatever the design, because the normal range of inlet (suction) hose diameters is 50-150 mm[28] (DSM75-100mm). Thus materials with sizes larger than the stated range will block the hose and lower the efficiency or result in ceasing of the suction operation, thus overworking the engine as in such conditions no flow of sludge through a hose takes place, while the engine is running continuously.

The community health education should include campaigns against people's habits of throwing such articles in pits. Also the

municipal authority should institute strict procedures as regards the condition of the pit contents acceptable for emptying and fine the owner of the latrine which may happen to contain such materials.

The community ought to be clearly informed on the truck order system, so as to make their orders well in advance. (When the pits are about two thirds full). This will give the municipal organizers enough time for making necessary arrangements for emptying before the pits are full.

5.4.0. MODIFICATION OF PIT LATRINE DESIGN/CONSTRUCTION SO AS TO SUIT THE EMPTYING PROCESS.

Traditionally thepreferreddesign is a large pit 3 - 4 metres deep and 2 - 3 metres in diameter (or rectangular) lined with blockwork or masonry (some of the pits are lined with oil drums). It is covered with a concrete slab cast in situ, with a rectangular squattig hole minimum dimension (150 mm x 120 mm). The modification in design of latrines for Dar-es-Salaam was proposed by the Consulting Engineers, (Howard Humpereys and Partners). The drawing is attached in Figure 22. A pilot scheme has been constructed.

The design is considered suitable for emptying purposes using the proposed truck type due to the fact that the base slab is cast with provision of an opening sized 400 mm x 400 mm to be covered later by a squat slab 600 mm x 600 mm which is cast separately.

When the emptying operation is to take place, the squat slab is removed so that the equipment for agitation of the sludge layer and the suction hose for subsequent withdrawal of pit contents are placed into the pit through this opening. The squat slab is

replaced on its original position after the completion of operations.

It is suggested that the pit volumes be reduced to about $2m^3$ and the frequency of emptying increased in order to avoid sludge compaction problems. Appendix 1. shows the criteria and calculations on which the proposed volumes are based.

The municipal authorities in collaboration with other responsible institutions, for example, the Ministry of Lands, Housing and Urban Development, should enforce the adoption of such designs in areas where new housing projects are under construction, particularly, in semi-urban areas in which "Site and Services" schemes are undertaken.

5.5.0 CONTINUOUS EVALUATION.

Records should be properly kept on how the whole system is managed. This will cover social, technical and organizational aspects and will help to assess the achievements accrued and any improvement required or favoured in the long term planning.

The evaluation should be carried out on different sites by skilled personnel, including technicians, sociologists, health officers, financial and management officers, and the information collected compared between these areas. An example of a data format form for the structure of latrines and emptying process is attached in table 7 .

CHAPTER 6.

6.0. CONCLUSIONS AND RECOMMENDATIONS

From the review and study of various aspects it was learned that:

(1) The local techniques used by private contractors for pit emptying are unhygienic to operatives and the whole community at large, inconvenient and costly to latrine users.

(2) The sludge (excreta) that had accumulated in pit latrines over five or more years is likely to be similar to a well compacted silt.

(3) It is difficult to empty old pit latrine contents effectively by using the existing type of vacuum tankers, mainly due to the existence of the hard sludge layer at the bottom and the blockages which occur in the first length of suction hose when attempting to suck non-excreted materials (debris) which are thrown into the pit.

(4) The compacted sludge layer could not be broken down by either a high pressure jetting or blackflushing.

(5) The study of rheological properties of sludge have led to the proposals of incorporating mechanical agitators in emptying operations for the disintegration of the compacted layer and effecting thorough mixture of the pit contents, thus improving the flow and pumpability characteristic.

(6) Further proposals for modification of vacuum tankers, so as to improve their capacities to empty pit latrines include: the injection of air into a suction hose from the vehicle's exhauster; increasing the vehicle capacity, (horse power) and uprating the vehicle pump to a 40 h.p. unit to be tested in conjunction with a 150 mm diameter hose.

(7) The sludge compaction in pits is fairly rapid in the first 1 - 3 years thus the proposals for sizing of new pits are based on a 3 year desludging cycle.

(8) Diaphragm pumps have the ability to pump any fluid that will flow; with the improved sludge pumpability properties, these types of pumps would be useful in emptying pit latrines effectively.

(9) The proposed night soil digestion and composting processes should be considered basically as methods of treatment and disposal rather than as biogas and manure -producing units. The methods can also greatly reduce the spread of intestinal diseases to a large extent as they would be the most hygienic methods amoung the different low technological disposal systems that are known to be operating in developing countries.

(10) The use of digesters and composted manure should be initially confined to Institutions where it will enable the understanding of possible technical and social problems likely to be faced in the field.

(11) Successful and effective emptying operations will be achieved by proper municipal organizational structure and incorporation of community education and participation in the whole programme.

(12) In Dar-es-Salaam, the cost of removing one load ($4.5m^3$) by truck is about $ 17 whereas the municipal authority charges about $ 4 - 5 per load. For comparison purposes the local contractor would charge $ 50-75 per latrine desludged.

RECOMMENDATIONS

(1) It is suggested that further detailed field studies of sludge properties covering a wide range of aspects (physical and chemical) be carried out to supplement the available information.

(2) The proposed modifications to pit emptying equipment be adopted and field tests carried out in order to assess their performance and effect necessary adjustments.

(3) It is recommended that in the meantime a diaphragm pump-trailer system be introduced to replace the vacuum truck system for pit emptying and the latter be confined to cesspool emptying until the appropriate truck is identified and manufactured.

(4) The establishment of night soil treatment plants be based on pilot schemes initially in the study area so as to evaluate their performance and the effects of environmental factors on their operation before embarking on a large scale programme.

(5) The municipal authorities should review the charges for truck pit emptying services due to the ever rising fuel and spare part costs or else the government is bound to subsidize heavily for the services.

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S. K. RUNYORO.

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APPENDICES

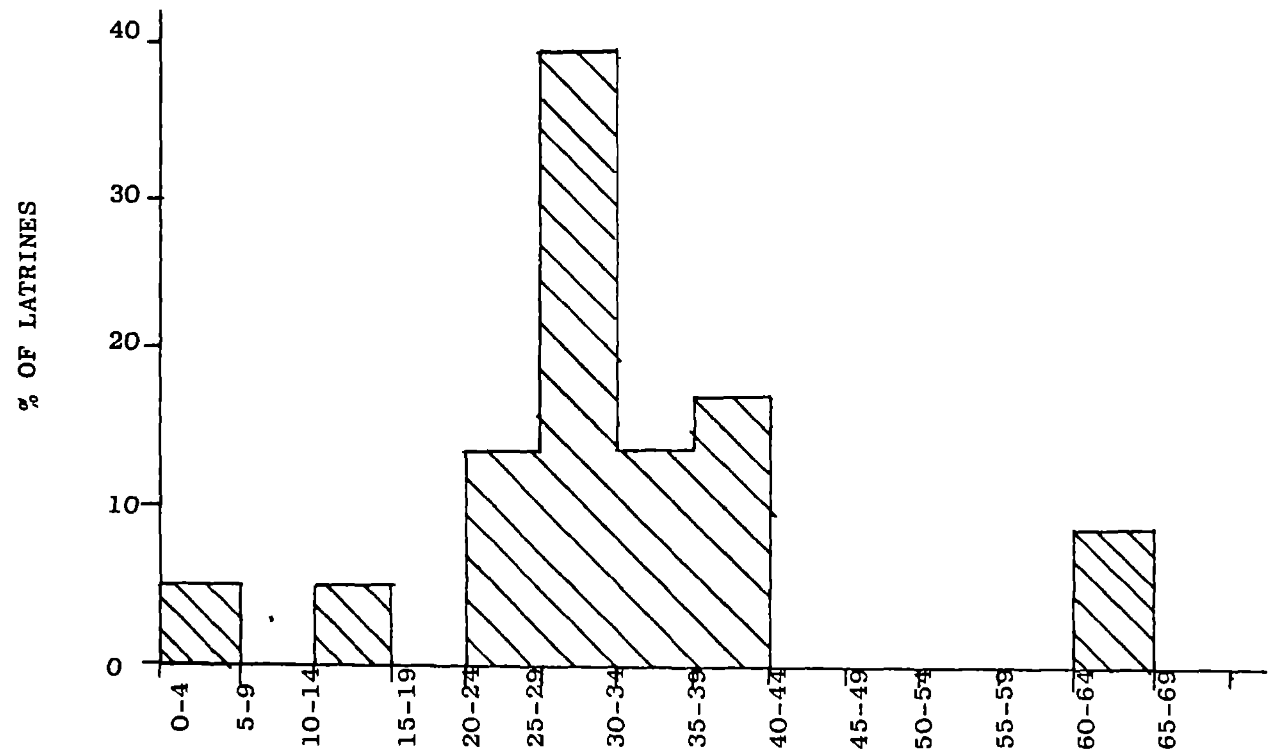
TABLE 6.

PROPERTIES OF PIT LATRINE SAMPLES COLLECTED FROM TANZANIA

SAMPLE NUMBER	YIELD STRESS (τo) (Pa)	DENSITY (Kg/M^3)	MOISTURE CONTENT (%)	SAND (%)	ORGANIC MATTER (%)	ACCUMULATION RATE (LITRES/PERSON/ YEAR	ACCESS FROM ROAD (M)	LARGE PARTICLES.
1	93	1750	28	67	5	-	20	none
2	23	1560	36	52	12	-	-	
3	74	1660	34	63	3	(130)	34	none
4	7	1500	41	48	11	-	30	old shoe rags
5	182	1370	54	41	5	18	27	rags
6	163	1340	53	34	13	39	27	none
7	58	1110	74	4	22	-	-	
8	132	1174	26	63	11	22	27	plastic bags
	31	1330	49	28	23	17	27	rags, sacking
9	109	1350	52	35	13	9	-	stones
10	54	1200	67	20	13	(132)	-	none
11	39	1610	34	56	10	36	-	rags, plastic bags
12	(291)	1400	47	39	14	(234)	23	rags, old shoes, wood
13	78	1280	66	(37)	( )	(80)	26	wood
14	221	1480	44	49	7	17	27	rags, paper
15	140	1310	59	35	6	25	27	none
16	81	1700	33	67	0	(83)	35	none
17	(458)	1310	58	34	8	(87)	25	none
18	29	1410	47	40	13	42	35	none
19	124	1390	49	39	12	(88)	10	none
20	39	1360	49	34	17	56	28	none
21	116	1340	50	31	19	34	35	none
22	62	1550	33	47	20	(119)	60	none
23	43	1590	32	51	17	47	30	paper
24	198	1430	47	44	9	25	20	none
25	132	1450	40	39	21	30	0	wood, sacking
26	202	1570	37	54	9	(115)	60	rags, wood, brick,
27	252	1400	53	46	1	35	35.	none

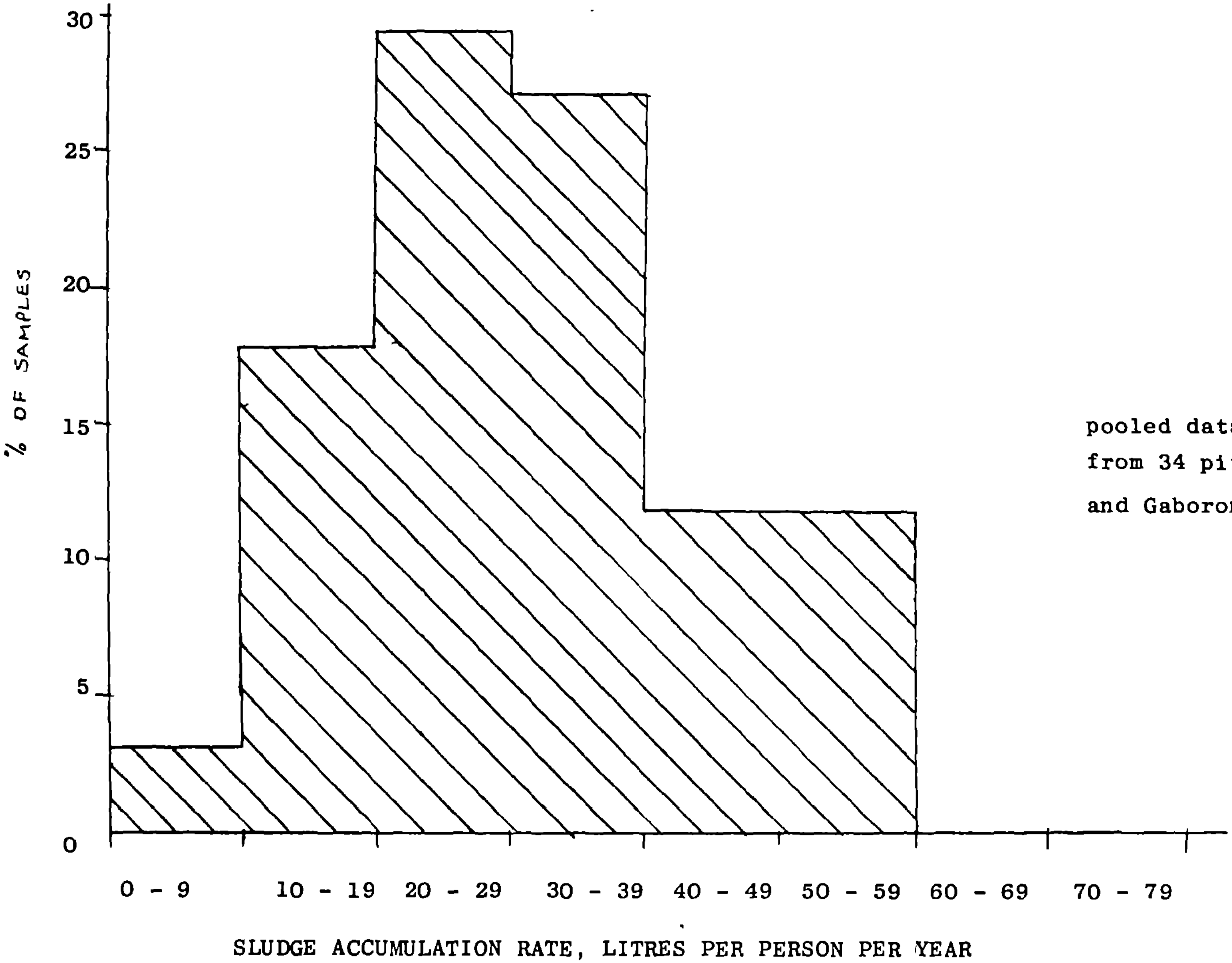
NOTES : (1) Figures in brackets ( ) indicate too high values/doubtful.
(2) The yield stress (τ_o) is determined from a power law : $\tau = k \gamma'^n$ where k and n are constants predetermined for each set.
(3) Source: Reference 27.

Figure 19 - Access Distances in Dar Es Salaam.



Data from 23 latrines

Figure 20. Sludge Accumulation Rate [27]



pooled data
from 34 pits in Dar Es Salaam
and Gaborone.

Figure 21 - Variation of Yield Stress with Time[27]

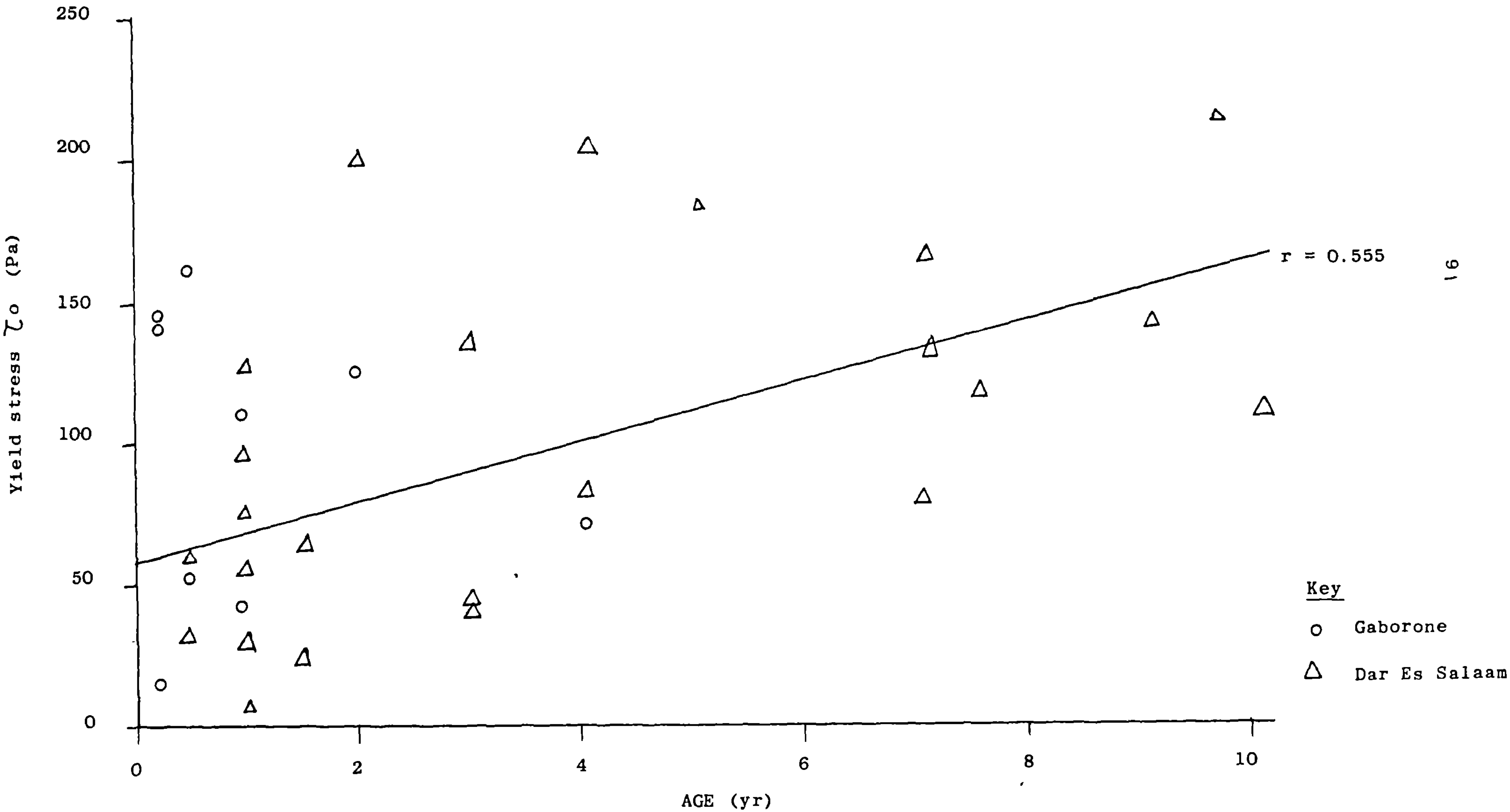


TABLE 7.

PIT LATRINE STRUCTURE AND EMPTYING DATA FORMAT FORM.

DESCRIPTION	SITES			
	1	2	3	4
Pit dimensions (Metres)				
Width				
Length				
Depth				
Depth of excreta from surface				
Depth to water table				
Usage (constant use)				
Pit lining material				
Soil type				
Surface drainage (away/toward)				
Superstructure material				
Ventilation pipe diameter (mm)				
Distance from equipment/Roadway (m)				
Types of Equipment				
Set up time (minutes)				
Emptying time (minutes)				
Dismantle time (minutes)				
Total time (minutes)				
Total volume emptied (m^3)				
Emptying rata (total min/m^3)				
Moisture Content (%)				
COMMENTS:				

SOURCE: WORLD BANK - FIELD TESTS REPORT.

APPENDIX 1.

SIZING OF PIT LATRINES (SUBSTRUCTURE) - DSM

The proposed size of the pit is based on a 3 year desludging cycle

- Rate of excreta accumulation = $0.03m^3$/hd/yr.
- Average number of users per household = 11*

∴ Volume of excreta = 0.03 x 11 x 3 years

= $0.99m^3$

Using a sludge bulking factor of 0.8

$$\text{Volume} = \frac{0.99}{0.8} = 1.24m^3\text{/ Latrine/ 3 years.}$$

The pit should be emptied when it is 2/3 full.

$$\text{Pit volume} = \frac{3}{2} \times 1.24 = 1.86m^3$$

Allowing for the volume of water which is used for anal cleansing (say 10% of volume)

∴ The design volume = $2.0m^3$

Dimensions could be : length = 1.5 m
width = 1.0 m
depth = 1.3 m

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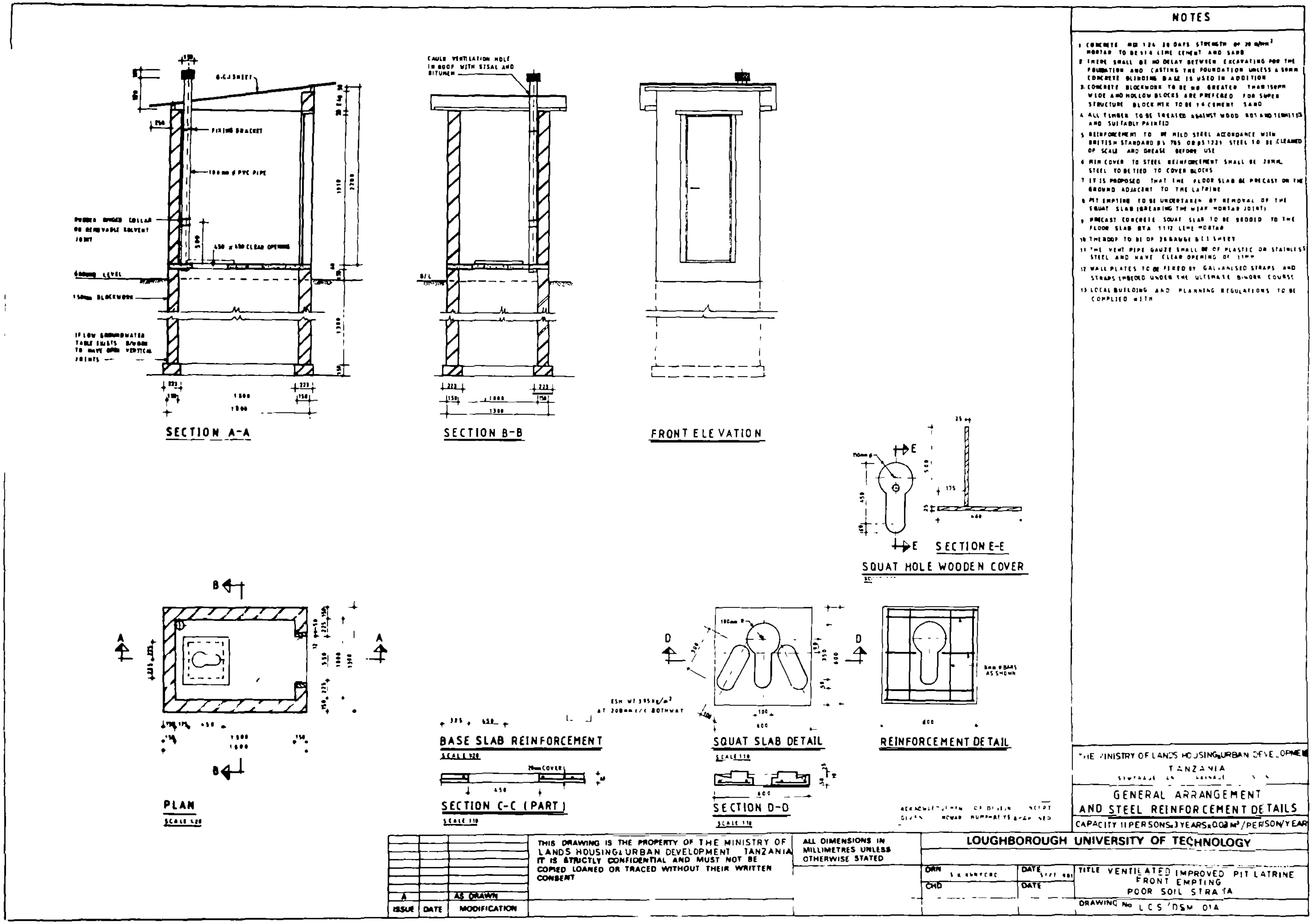
*FROM SURVEYS CARRIED OUT BY THE MINISTRY OF LANDS, HOUSING AND URBAN DEVELOPMENT 1979

Fig. 22


SECTION A-A
SECTION B-B
FRONT ELEVATION
SQUAT HOLE WOODEN COVER
SECTION E-E
PLAN
BASE SLAB REINFORCEMENT
SECTION C-C (PART)
SQUAT SLAB DETAIL
SECTION D-D
REINFORCEMENT DETAIL
NOTES
1 CONCRETE MIX 1:2:4 28 DAYS STRENGTH OF 20 N/mm²
MORTAR TO BE 1:1:6 LIME CEMENT AND SAND
2 THERE SHALL BE NO DELAY BETWEEN EXCAVATING FOR THE FOUNDATION AND CASTING THE FOUNDATION UNLESS A 50mm CONCRETE BLINDING BASE IS USED IN ADDITION
3 CONCRETE BLOCKWORK TO BE NO GREATER THAN 150mm WIDE AND HOLLOW BLOCKS ARE PREFERED FOR SUPER STRUCTURE BLOCK MIX TO BE 1:6 CEMENT SAND
4 ALL TIMBER TO BE TREATED AGAINST WOOD ROT AND TERMITES AND SUITABLY PAINTED
5 REINFORCEMENT TO BE MILD STEEL ACCORDANCE WITH BRITISH STANDARD BS 785 OR BS 1221 STEEL TO BE CLEANED OF SCALE AND GREASE BEFORE USE
6 MIN COVER TO STEEL REINFORCEMENT SHALL BE 20mm. STEEL TO BE TIED TO COVER BLOCKS
7 IT IS PROPOSED THAT THE FLOOR SLAB BE PRECAST ON THE GROUND ADJACENT TO THE LATRINE
8 PIT EMPTYING TO BE UNDERTAKEN BY REMOVAL OF THE SQUAT SLAB (BREAKING THE WEAK MORTAR JOINTS)
9 PRECAST CONCRETE SQUAT SLAB TO BE BEDDED TO THE FLOOR SLAB BY A 1:1:12 LIME MORTAR
10 THE ROOF TO BE OF 28 GAUGE G.C.I. SHEET
11 THE VENT PIPE GAUZE SHALL BE OF PLASTIC OR STAINLESS STEEL AND HAVE CLEAR OPENING OF 1.1mm
12 WALL PLATES TO BE FIXED BY GALVANISED STRAPS AND STRAPS EMBEDED UNDER THE ULTIMATE B/WORK COURSE
13 LOCAL BUILDING AND PLANNING REGULATIONS TO BE COMPLIED WITH
THE MINISTRY OF LANDS HOUSING & URBAN DEVELOPMENT
TANZANIA
GENERAL ARRANGEMENT
AND STEEL REINFORCEMENT DETAILS
CAPACITY 11 PERSONS x 3 YEARS x 0.03 m³/PERSON/YEAR
THIS DRAWING IS THE PROPERTY OF THE MINISTRY OF LANDS HOUSING & URBAN DEVELOPMENT TANZANIA IT IS STRICTLY CONFIDENTIAL AND MUST NOT BE COPIED LOANED OR TRACED WITHOUT THEIR WRITTEN CONSENT
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY
A AS DRAWN
ISSUE DATE MODIFICATION
DRN
DATE
CHD
DATE
TITLE VENTILATED IMPROVED PIT LATRINE FRONT EMPTING POOR SOIL STRATA
DRAWING No LCS/DSM 01A