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Family scale rural water treatment plant: intermittent slow sand filtration

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FAMILY SCALE RURAL WATER TREATMENT PLANT:

INTERMITTENT SLOW SAND FILTRATION

Leonard John Abrams

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 1989

I DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



Third day of April 1989

II ABSTRACT

A simple, low cost, family scale water treatment plant for rural use, constructed from a 210 litre drum using local materials, is tested for bacteria removal. The plant incorporates sedimentation, intermittent slow sand filtration, and a 24 hour storage cycle. Bacteria reduction of the order of 10^4 is achieved, with mean treated water total plate counts of 294/ml and total coliform counts of 1.63/100ml. The mean treated water turbidity is 0.27 NTU. The slow sand filtration process is discussed and an annotated bibliography included.

III DEDICATION

This work is dedicated to those rural families
who will most benefit from it.

IV ACKNOWLEDGEMENTS

I wish to acknowledge with thanks the encouragement and financial assistance provided for the project by the Standard Bank and in particular Mr John Gaunt. I also appreciate very much the support given me by the directors and staff of Steffen Robertson and Kirsten. The project would not have been possible without the support and guidance of the Department of Civil Engineering of the University of the Witwatersrand.

A special word of thanks must go to my wife Karen and the children for putting up with the "bug machine" for a year, especially to young Paula and Patrick who subjected the pilot plant to various abusive tests of their own.

V CONTENTS

I DECLARATION ii

II ABSTRACT iii

III DEDICATION iv

IV ACKNOWLEDGEMENTS v

V CONTENTS vi

1. INTRODUCTION: PROJECT OBJECTIVES 1

2. LITERATURE SURVEY 3

3. RURAL WATER 4
   - 3.1 Introduction 4
   - 3.2 The social costs of rural water 4
   - 3.3 Rural water consumption 7
   - 3.4 Health and rural water 9
   - 3.5 Determining water quality 12

4. SLOW SAND FILTRATION 14
   - 4.1 History 14
   - 4.2 Physical processes 14
     - 4.2.1 Straining 15
     - 4.2.2 Interception 15
     - 4.2.3 Inertia 15
     - 4.2.4 Sedimentation 15
     - 4.2.5 Diffusion 16
     - 4.2.6 Hydrodynamic forces 16
     - 4.2.7 Flocculation 16
     - 4.2.8 Filter blocking 18
     - 4.2.9 Filter head loss 19
     - 4.2.10 Primary sedimentation 20
   - 4.3 Biological processes 21

4.4 Design criteria 22
4.4.1 Flow rate 23
4.4.2 Filter media 24
4.4.3 Shading 24
4.4.4 Operation and maintenance 25
4.4.5 Community participation 26

5. INTERMITTENT SLOW SAND FILTRATION 27
5.1 Introduction 27
5.2 Design criteria 28
5.3 Design 30
5.3.1 The drum 30
5.3.2 Cutting and preparation of the drum . . 30
5.3.3 Fittings 31
5.3.4 The reservoir 32
5.3.5 The filter section 32
5.4 Operation 33
5.4.1 Commissioning 33
5.4.2 Daily use 34
5.4.3 Maintenance 34

6. TESTING PROGRAMME 36
6.1 Introduction 36
6.2 Tests 37
6.2.1 Turbidity 38
6.2.2 Temperature 38
6.2.3 Conductivity 38
6.2.4 Faecal coliform bacteria 38
6.2.5 Total plate count 39
6.2.6 Dissolved oxygen determination 40
6.3 Routine testing 40
6.4 Recovery test 42
6.5 Stagnation test 42
6.6 Introduction of charcoal layer 43

7. RESULTS 44
7.1 Introduction 44
7.2 Tests 44
7.2.1 Turbidity 44
7.2.2 Temperature 47
7.2.3 Conductivity 48

7.2.4 Faecal coliform bacteria 48
7.2.5 Total plate count 50
7.2.6 Dissolved oxygen 50
7.3 Routine testing 50
7.4 Recovery test 51
7.5 Stagnation test 51
7.6 Charcoal layer TDS reduction 52

8. FIELD PILOT PLANTS 53
8.1 Lekhema, Winterveld 53
8.2 Mafefe continuous flow pilot filter 54
8.2.1 Introduction 54
8.2.2 Design 54
8.2.3 Results 58

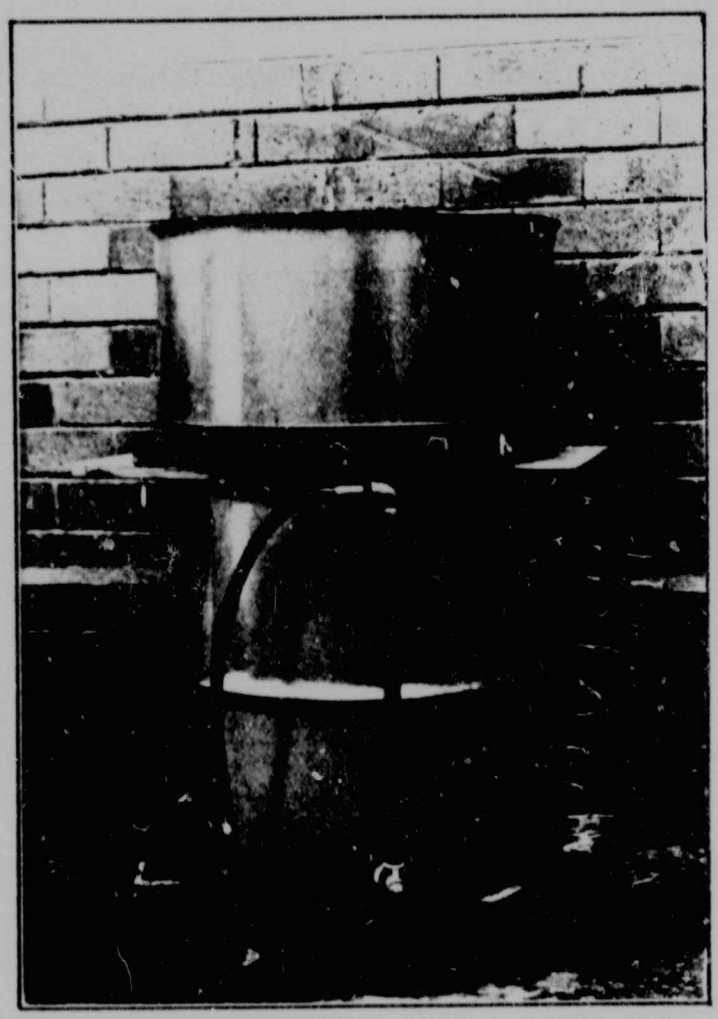
9. CONCLUSIONS 59

APPENDICES

Appendix A Listed results
Appendix A.1 Complete results
Appendix A.2 Complete treated water results
Appendix A.3 Complete raw water results
Appendix A.4 Normal treated water results
Appendix A.5 Dissolved Oxygen results
Appendix B Field test results
Appendix B.1 Lekhema field test results
Appendix B.2 Mafefe field test results
Appendix C WHO water quality tables

REFERENCES

BIBLIOGRAPHY



A SMALL SCALE RURAL WATER TREATMENT PLANT

1. INTRODUCTION: PROJECT OBJECTIVES

The provision of domestic water for rural families is a problem which is being addressed with increasing urgency throughout the third world. In the course of the present International Drinking Water Supply and Sanitation Decade (1981 - 1990) millions of dollars have been spent on basic services. Disquietening voices are beginning to be heard, now that the decade is drawing to a close, that little headway is being made (Abidjan Conference, World Water, November 1986). There remains little prospect that many rural dwellers will enjoy the benefit of a treated water supply. The purpose of this project was therefore to develop a low cost, appropriate method of treating water on a family scale.

The objectives of the project were to design a plant to meet the following criteria:-

* To provide drinking and cooking water (50 litre per day) for one family,
* Simple operation,
* Minimal maintenance requirements,
* Constructed from locally available materials,
* Minimum local skills required to construct,
* The plant must be acceptable to users,
* The treated water must be acceptable to users,
* The bacteriological quality must be substantially improved, without the use of chemicals,

* The cost must be as low as possible.

The final design comprises a 210 litre galvanized iron drum cut and fitted as indicated in Fig. 5.1. The design meets all the criteria set out above. The treatment method includes sedimentation and an adaptation of conventional slow sand filtration (SSF). The plant operates on a batch loading principle with intermittent flow. Because conventional slow sand filtration produces an inferior quality effluent if it is not operated continuously, and because the design operates at a daily equivalent rate of 10% of conventional SSF, the term intermittent slow sand filtration (ISSF) is used to describe the process.

This report includes a discussion of health related aspects of rural water and water quality guidelines. The theory of the processes of sedimentation and slow sand filtration, including the physical and biological action, is discussed, after which the design of the plant is explained in detail. A nine month monitoring programme is described, including tests performed on the plant and the methodologies used. Finally, results are reviewed and conclusions drawn indicating areas where further research is required.

2. LITERATURE SURVEY

Using the WATERLIT service of the CSIR, a literature survey was conducted which produced 206 references relevant to water supplies in developing countries, with special attention given to treatment and slow sand filtration. From these some 45 articles and publications were acquired for examination. The contents of these and other references are summarized in the annotated bibliography.

The literature refers to small filter plants (Alagarsamy & Ghandirajan, 1981) but no reference to research conducted into the effectiveness of small scale slow sand filtration was found.

3. RURAL WATER

3.1 Introduction

Rural water usage in the third world is a topic of immense importance with implications beyond the borders of the rural communities involved. Water quality and quantity affect every aspect of rural life - how people use their time, social and cultural aspects, health, agriculture, animal husbandry, wealth generation, and general quality of life. These factors have direct influence on national economics because drought has the effect in many third world countries of increasing their dept and creating dependance on international aid.

The social costs of water to rural communities can be very high because of the haulage time and energy required, as well as the cost of lost productivity as a consequence of water related disease. The impact of rural water on health needs to be clearly defined in order to combat water related diseases in the field. Water consumption varies from community to community and depends on availability, haulage distance and local custom. The quality of water available to communities also varies greatly depending on the source. Very few natural sources remain uncontaminated when used as regular water collection points.

3.2 The social costs of rural water

The cost of water in rural areas needs to be determined if an effective assessment is to be made of cost benefits of any proposed change to an existing supply. Few studies have been made of this very important aspect. Water collected by rural people is seldom paid for in cash but to assume that it has no cost would be incorrect. A study of the social

cost of rural water in Nigeria (Akintola, Areola, & Faniran, 1980) reveals the price paid, mostly by women, for domestic water.The study was conducted in Oyo State which has a mean annual precipitation of 1000 - 1250mm. The average minimum and maximum daily consumption per capita were 21 l and 26 l respectively. 75% of households reported that their main source of water dried up during the dry season when 92% resort to digging in river beds to obtain water. The following tables which are taken to be representative of semi-arid conditions indicate the daily effort which is expended in fetching water.

Table 3.1 Sources of water supply at different seasons of the year

Sources	Households using sources (%)		
	All year	Dry season	Rainy season
Well	--	6.6	14.4
Spring	24.7	3.7	82.2
Pond	2.8	3.7	78.1
Dugout stream bed	0.3	91.9	0.3

Table 3.2 Use of water obtained from different sources

Use	Households (%)			
	Well	Streambed	Spring	Pond
Washing	9.7	85.3	5.3	0.0
Cooking	1.9	9.3	87.5	1.6
Drinking	5.6	5.3	18.1	71.3
Livestock	0.0	0.0	7.2	57.5

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Table 3.3 Labour force involved in fetching water

Family member	% Households in which member participate	Average no.of trips per day
Youngest wife	98.4	5.25
Second wife	70.6	4.40
First wife	7.2	4.83
First child	45.9	2.89
Second child	12.5	3.10
Third child	2.2	1.86

Table 3.4 Distances to main sources of water supply

Distance (km)	Households (%)
Less than 1.5	7.1
1.5 - 3	92.0
3 - 5	0.9

Table 3.5 Time spent in fetching water

	Households (%)	
Hours per trip	Dry season	Rainy season
Less than 1	9.9	35.6
1 - 2	62.2	61.0
2 - 3	26.5	3.4
More than 3	1.6	---
Mean	1.98 hr	0.86 hr

Some indication of the social costs of rural water in South Africa are given in a study of household water consumption in the Inadi ward, KwaZulu (Alcock, 1986). The mean daily per capita consumption was 15,6 l with an average per capita consumption of drinking water of 2,3 l . A daily average of three trips was said to be common.

In addition to the energy and time spent in collecting water, a large amount of time is spent incapacitated due to water related diseases. Referring to the Nigerian study cited above, where the water borne parasite Guinea Worm is common, 59% of the population had suffered at one time or another. Of those who had suffered, an average of 126 days per year were unproductive as a result. (Health related factors of rural water are discussed in greater detail later in this paper.)

The social costs of water should be assessed in terms of the time and energy expended in fetching water and the effects of water related disease on community health. This cost may be measured in terms of the time lost which could otherwise have been spent in active and productive participation in the community. The social costs of water in Southern Africa need to be researched in greater depth.

3.3 Rural water consumption

The quantity of water consumed by rural people who depend on natural sources for their supply, is limited by the availability of water at the source and by the cartage distance between the source and the user's home. Water sources may include springs, streams, shallow wells, boreholes and river bed abstraction. Both Alcock (1986) and Akintola et al (1980) indicate that different sources are preferred by different users and that water is reused for different purposes within the household.

Water usage and the perception of water quality varies from community to community (Guideline for Drinking Water Quality, Volume 1, WHO, 1984). Alcock (1986) quotes a daily drinking water consumption of 2,3 l which constitutes 15% of the total consumption (KwaZulu, Natal). Other uses of water

include cooking, personal hygiene and clothes washing. The average total daily per capita consumption was 15,6 l. This survey indicates the very low consumption rates of rural communities when water has to be carried to the home.

Determining design rates of consumption is complicated by the fact that any alteration of the existing supply status will change the consumption patterns.

J.C. De Korte, in an unpublished paper dated November 1987, quotes the following consumption figures (in litre per capita per day [l/c/d]) from a WHO report of 1970:-

Table 3.6 Rural water consumption (WHO, 1970)

Type of supply	Consumption l/c/d	Range l/c/d
Communal water point		
> 1 000 m	7	5 - 10
500 - 1 000 m	12	10 - 15
< 500 m	20	15 - 25
Communal standpipe		
< 250 m	30	20 - 30
Yard connection		
tap in yard	40	20 - 80
House connection		
single tap	50	30 - 60
multiple tap	150	70 - 250

Alcock (1986) quotes consumption figures from unpublished, mainly official, sources for rural areas with water collected from source (see table 3.7).

Table 3.7 Daily per capita water consumption.

Location	Litres
Lebowa	20
Lesotho	18 - 24
KwaZulu	11
Transkei	10
Ciskei	9

3.4 Health and rural water

According to the publication - Rural Water Supply in China, IDRC (1981) - "Of all diseases affecting rural populations, those that are water related are the most important." The effect of the availability of water of sufficient quantity and suitable quality on the health of communities is not restricted to water borne and water washed diseases, malnutrition can also result from the effects of drought on agriculture and animal husbandry. It is therefore clear that virtually every factor of rural life is dependent upon water and that no community will be able to maintain even the most basic level of health if it does not have water in sufficient quantity and of adequate quality.

The effects of water on rural health can be divided into the following categories, according to Sibony (1981), Van der Veen (1980), Windle-Taylor (1980), and the World Health Organisation's "Guidelines For Drinking Water Quality" (1984):-

Nutritional : drought - food shortages

Water borne diseases : water is a passive vehicle for faecal pollution and a source of pathogenic bacteria, viruses and protozoa.

Water washed diseases : insufficient supply of water is available to maintain personal hygiene.

Water based : infecting agents are ingested or enter the body by penetrating the skin and mucous membranes.

Water related insect vectors : when diseases are spread by insects which breed in water e.g. malaria and yellow fever.

Inorganics : when trace elements present in too small or too great concentrations give rise to endemic deficiencies or poisoning. The sources may be natural or the result of manmade pollution.

Diseases or symptoms associated with the above categories are as follows:-

Nutritional : Malnutrition

Water borne diseases : **Viruses** e.g. infectious hepatitis, **Bacteria** e.g. cholera, typhoid and paratyphoid fevers, bacillary dysentery, gastro-enteritis, leptospirosis. **Protozoa** e.g. amoebic dysentery

Water washed diseases : scabies, skin sepsis, yaws, leprosy, lice and typhus, trachoma, conjunctivitis, bacillary dysentery etc.

Water based diseases : bilharzia, leptospirosis, schistosomiasis, guinea worm.

Water-related diseases : yellow fever, malaria, sleeping sickness, dengue etc.

Water borne diseases : water is a passive vehicle for faecal pollution and a source of pathogenic bacteria, viruses and protozoa.

Water washed diseases : insufficient supply of water is available to maintain personal hygiene.

Water based : infecting agents are ingested or enter the body by penetrating the skin and mucous membranes.

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Water-related diseases : yellow fever, malaria, sleeping sickness, dengue etc.

Chemical elements : below are some of the effects of the more important elements, based on tables extracted from the World Health Organization Guidelines for Drinking Water Quality. (See appendix C.)

Chloride : high concentrations give unpleasant taste and affects the secretion of gastric juices and digestion.

Sulfates : magnesium sulphate and sodium sulphate cause diarrhoea. The concentrations of these sulfates must therefore be kept low.

Iron in high concentration causes discoloration and taste problems.

Copper accumulation in the body due to high concentration in water is toxic.

Iodine is necessary for the production of thyroxine in the thyroid gland. Lack of iodine in drinking water is the main cause of goitres. A minimum of 10mg/l is recommended in drinking water.

Fluoride is important in the formation of teeth and bones. Endemic tooth decay occurs where concentrations are less than 0.5mg/l. However, where concentrations are greater than 1.5mg/l, mottling of teeth may be observed. At 3.0 - 6.0mg/l skeletal fluorosis may occur and when 10mg/lis exceeded crippling fluorosis may ensue.

Nitrite and nitrate : Usually of organic origin, indicate source pollution. Nitrite is harmful to health; in high concentrations it combines with

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