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Removal of iron from groundwaters

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INTRODUCTION

Groundwater is an important source of relatively inexpensive water supply for domestic and industrial purposes; in most cases no treatment is normally required other than disinfection. It is therefore not surprising that most governments in developing countries have embarked on extensive programmes of rural water supply based on groundwaters.

However, certain chemical substances notably iron and manganese are sometimes present in excessive amounts; consumers complain about staining effects on laundry, cooking utensils plumbing fixtures, and about bitter or metallic taste. These consumers then revert to their old polluted sources of water. Iron is usually present in solution in the ferrous (Fe II) form but other forms may also be present. Such groundwater, which may be clear and bright initially, on exposure to air, becomes discoloured opalescent due to the oxidation of the ferrous iron to insoluble or colloidal ferric hydroxide.

A study of the Drinking Water Quality of Boreholes in the Rural areas of Ghana completed by the Water Resources Research Unit of the Council of Scientific and Industrial Research (CSIR) in 1974 showed that over 30% of the boreholes had water in which iron concentration exceeded 1.0mg/l, the then WHO International Standard for Drinking Water (1971) maximum permissible level. The range of concentrations reported for iron was zero to 26.5mg/l.

The Ghana Government in collaboration with International Agencies like the United Nations Development Programme (UNDP), United Nations Children's Fund (UNICEF), the Canadian International Development Agency (CIDA) and the German Government is currently undertaking an extensive rural water supplies programme which include the sinking of thousands of wells to be equipped with hand-pumps. Various non-governmental organisations (NGO's) such as World Vision International, Catholic Relief Services and Adventist Development and Relief Agency (ADRA) are also assisting in rural water supply schemes. Currently in Ghana, there are over 6,000 bore-holes with handpumps in remote areas all over the country. Given that 30% of the ground-water supplies may have excessive iron content which may lead to their rejection by consumers the availability of a simple low cost system for iron removal would make an invaluable contribution to the success of the rural water supply programme. Since many developing countries are reported to have similar groundwater quality problems, appropriate technologies for the removal of iron from groundwater developed in Ghana are likely to be of interest in many developing countries.

The Environmental Quality Engineering Division of the Department of Civil Engineering of the University of Science and Technology, Kumasi has been engaged inthe development of small scale systems for iron removal from groundwaters since 1976. The project was initially sponsored jointly by the International Development Research Centre (IDRC), Ottawa, Canada and the University of Science & Technology, Kumasi.

Objectives of Project

The objectives of the Groundwater Iron Removal Project included the following:

i. to review available technology for small scale iron removal from groundwater in rural areas

ii. to improve by adaptation and/or innovation of existing methods of iron removal and make them applicable to village conditions in Ghana

iii. to determine in the laboratory and field the relative effectiveness of the developed systems or units for small scale iron removal

iv. to recommend future activities by which the more promising iron removal units can be manufactured either at the village level or industrial level to meet the demand for such units in Ghana.

FIELD SURVEY

In the development of a system for iron removal from groundwaters in rural areas, the project aimed at evolving technologies that would be appropriate to local rural conditions while at the same time promoting full community participation. To achieve this objective, a survey was undertaken to establish relevant local conditions. The specific objectives of the survey were:

i. to collect data on iron, pH, alkalinity, hardness and total solids to supplement available information on groundwater quality.

ii. to identify factors, including concentration of iron which led to the rejection of water by users.

iii. to determine the necessary range of conditions which the small scale iron removal units would have to cover.

The selection of communities for the field survey was done mainly by random sampling but care was taken to ensure that the selected communities were as evenly distributed as possible on a geographical basis.

Survey Methodology

To meet the objectives of the field survey, an approach based on Questionnaire, Water Quality Analysis and Physical inspection of boreholes was adopted. The questionnaire was in two parts; the first part dealt with the characteristics of the groundwater supply, namely, levels of service of boreholes and serviceability of pumps, and the second part, with user attitude and water use patterns. The questionnaire was designed to establish factors which led to the rejection of borehole water.

When a visit was made to a selected community, physical inspection of the boreholes was undertaken and information on type of handpump, year of installation, frequency of breakdown, etc. was recorded. The chief or a member of the town or village development committee was then interviewed and the questionnaire completed. These people were chosen because of their knowledge of developmental programmes in their communities. It must be noted that in all cases the interviewee was assisted by other members of the community who made sure that the information given represented a consensus. Thus the results from the interviews fairly reflected the views of the communities.

During visits samples were also collected from boreholes which were found in operation at the time of the visit. Analysis on pH and iron was performed on the spot using Hach pH Meter and Hach DR-EL Direct Reading Engineer's Laboratory Kit. The other parameters, namely, alkalinity, hardness and total solids were determined later at the Environmental Quality Engineering Laboratory at the University of Science & Technology, Kumasi.

Results of the Survey

Eighty-three towns/villages were visited, this represented about 44% of the number for the field survey. The number of boreholes seen was 187. Even though the coverage was not uniform for all the regions, nevertheless, all the then nine regions in Ghana were covered by the visits. Of the boreholes seen only 47 (34.6%) of the handpumps were found working at the time of the visits. Even these were reported to be very unreliable and to be breaking down very often. 44% of the bore holes were seen with broken-down handpumps and 21.4% had no pumps. Most of the communities expressed their willingness to use the boreholes if the pumps were put back into operation.

Water samples obtained from the 47 boreholes indicated an average iron concentration of 1.36mg/l in the range 0 - 19.0mg/l. High levels recorded were 9.0, 9.5 and 19.0mg/l. The boreholes which had these concentrations had been abandoned. It was also found from the survey that only 10.7% of the boreholes for which questionnaires were completed was unacceptable to the users in terms of the quality of the water. The levels of iron concentration ranged from 1.45mg/l to 4.0mg/l and the complaints were about odour, colour and taste of the water. The range of iron concentration in the remaining 89.3% which did not register any complaints on water quality was 0 - 4.0mg/l.

REVIEW OF AVAILABLE TECHNOLOGY

Available technology for the removal of iron from groundwaters was identified and reviewed through literature search, correspondence and an international visit. As a result of these activities, two iron removal units were selected for further work in Ghana. One was the Domestic Iron Removal Unit (DIRU) developed by the National Environmental Engineering Research Institute (NEERI), Nagpur, India and the other the Iron Removal Plant of capacity of 1000 liters per day (IRP-1000) developed by the Tamilnadu Water Supply and Drainage Board (TWAD), Madras, India. Both units were reported to be efficient and suitable for rural water supplies.

FIELD TESTING OF CANDIDATE SYSTEMS

The field testing involved studies aimed at selecting the best systems from standpoint of efficiency of iron removal, simplicity of operation and adaptability for further use under Ghanaian conditions. The candidate systems which were to be field tested were the 'DIRU' and IRP-1000. These were two systems identified through the review of available technology. Due to problems of identification of a suitable site for the IRP-1000 only the DIRU was field tested.

'DIRU'

The DIRU is a four-compartment cylindrical unit. The top two compartments contain coke or charcoal, the third compartment contains coarse sand supported over a layer of gravel and the fourth compartment is for the collection of the filtered water. The connection between the compartments is through perforated plates over which are retained the appropriate granular media. The design is such that the filter is not submerged during operation consequently some operational problems were likely to develop.

The unit which was constructed in the Faculty of Engineering Workshop, University of Science and Technology (U.S.T.), Kumasi, was installed for operation at the Kuntanase Health Centre, 28km from U.S.T. The borehole at the Centre was found fitted with a Monarch Handpump. The water from the borehole was found from studies to contain high levels of iron; concentration as high as 72 mg/l. were sometimes obtained.

The unit was initially operated under intermittent conditions. During visits to the site a number of bucketsful of water (about 20 on the average; capacity of bucket, 15 litres) were drawn from the borehole and poured through the unit, and the effluent was collected from the bottom compartment. This method of operation was chosen to simulate a situation where the unit would be used intermittently such as buckets of water containing excessive amounts of iron collected from a borehole would be poured through the unit.

The range of iron concentration in the borehole water was found to be between 8.5 and 72.0 mg/l. (average 42.0 mg/l) whilst that of the fittered water was between 0.25 and 11.5 mg/l. with an average of 4.9 mg/l. The range of percentage removals of iron was 56.5 to 99.5. Although high percentage removals were recorded for the 'DIRU' during the intermittent operation most of the effluent iron concentration were higher then 1.0 mg/l. the maximum permissible level by the WHO standard. It was concluded from the studies that although the DIRU might be efficient in the removal of iron, it was not found suitable for such high concentration (8.5 - 72.0 mg/l) as recorded at Kuntanase.

A method of continuous operation for a specified length of time was introduced to simulate a condition where raw water from a borehole fitted with a force pump is sprayed directly on to the unit on a continuous basis for a few hours at a time. Under this method of operation, water from the borehole was first drawn into a drum. From this drum the water was allowed to flow continuously through the test unit. The duration of each run was about two hours.

The range of the influent iron concentrations was 13.0 - 18.0 mg/l with an average of 15.8 mg/l and that of the effluent 0.3 - 0.17 mg/l with an average of 0.12 mg/l. These effluent concentrations were all within the maximum permissible levels set by WHO. The range of percentage iron removals permissible was 98.5 to 99.8%. These preliminary results indicated that the continuous operation was feasible and superior to intermittent operation.

DEVELOPED SYSTEMS

Based upon the results obtained and the operational condition of the testing of the 'DIRU',four modifications of the unit were developed. The names given to the four derived system were i. MODIRU - 1 ii. MODIRU - 2, iii. MODIRU - 3 and MODIRU - 4.
Their schematic representation can be seen in Fig.1. The basic difference between them, as a group and the 'DIRU' is the design of the filter units to operate under submerged condition in contrast to the design of non-submerged filters in the 'DIRU'.

MODIRU-1

This is a four-compartment cylindrical unit The top two compartments contain charcoal and are for contact aeration. Vents are provided on the to p compartment to promote aeration. The third compartment is a submerged filter containing coarse sand supported over a layer of gravel. The fourth compartment is for the collection and storage of the filtered water.

Unlike the DIRU, MODIRU-1 has no vents provided on the fourth compartment and the filter compartment is always submerged. The layout of MODIRU-1 is as shown in Fig.2.

Raw water from a borehole is sprayed over the top compartment of the unit. The water trickling through the charcoal bed in the top compartment to the second becomes aerated; it is further aerated when it drips through the second compartment. The submerged filter then filters the aerated water containing ferric precipitates.

MODIRU-2

This is a unit consisting of one module of MODIRU-1 followed by a cylindrical compartment containing a submerged filter. The submerged filter contains coarse sand supported over a layer of gravel.

DODIRU-3

MODIRU-3 is made up of one MODIRU-1 module operating in series with a two-compartment cylindrical unit consisting of a contact aerator and a submerged filter.

MODIRU-4

MODIRU-4 consists of two modules of MODIRU-1 units which have been arranged in series.

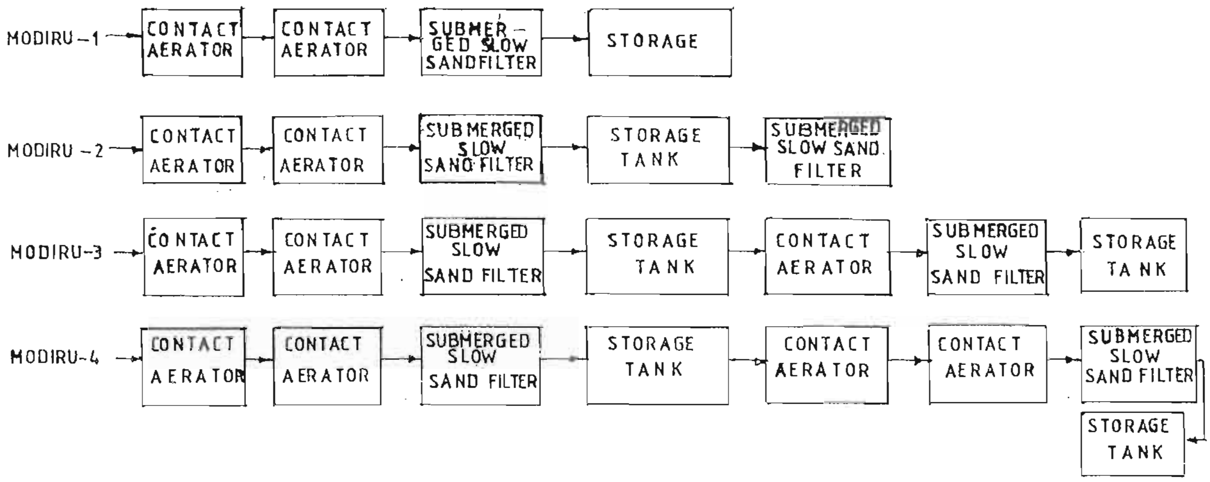

FIG 1 SCHEMATIC PRESENTATION OF PROPOSED SYSTEM

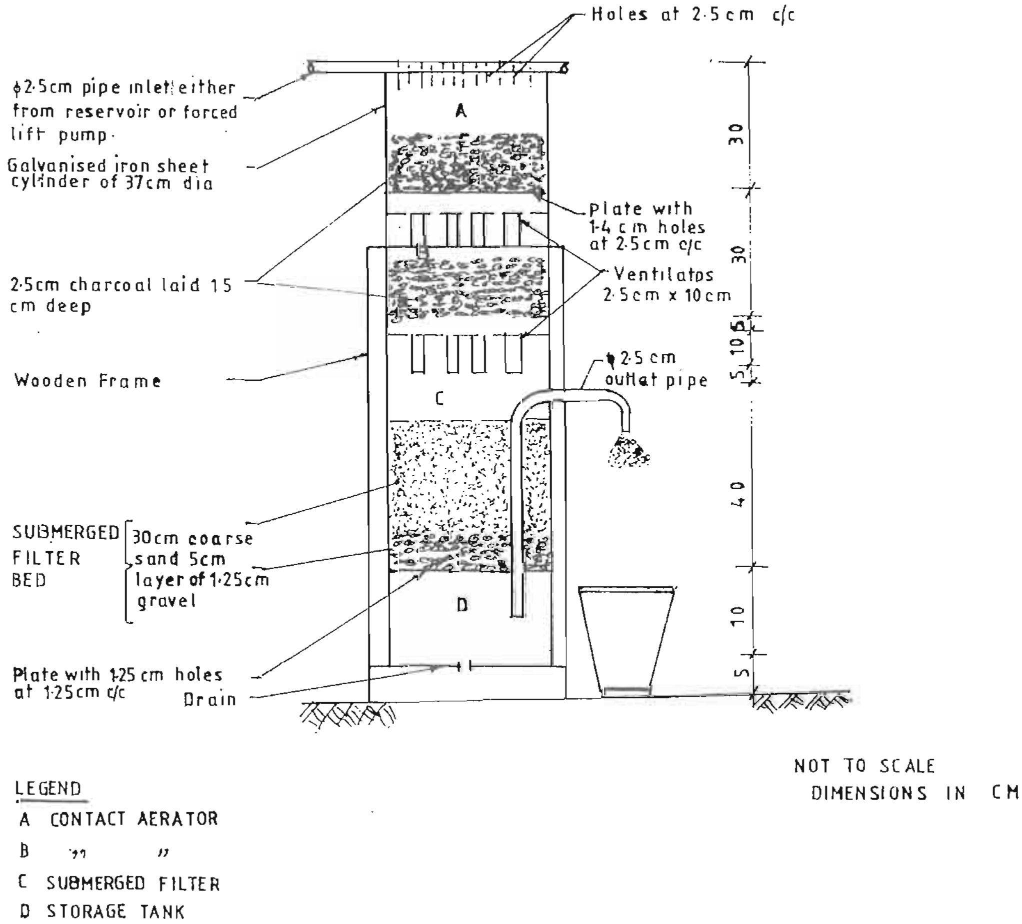

FIG. 2 MODIRU – 1

TABLE 1 SUMMARY OF THE RESULTS - MODIRU 1- AND MODIRU-4

Parameter	MODIRU - 1				MODIRU - 4			
	Influent Quality		Effluent Quality		Influent Quality		Effluent Quality	
	Range	Average	Range	Average	Range	Average	Range	Average
pH	6.74 6.85	6.8	6. 85- 7.0	6.9	6.7- 6.85	6.8	6.9 7.0	7.0
Iron (mg/l)	13.0- 18.0	15.9	0.02- 0.09	0.06	13.0- 18.0	15.9	0.05- 1.3	0.3
Alkalinity (mg/l)	38.0- 46.5	43.4	44.0 80.0	50.5	36.0- 46.5	43.1	53.5- 70.0	61.0
Hardness	25.0- 40.0	30.8	40.0- 50.0	41.7	30.0- 40.0	31.7	40.0 60.0	47.5
Total Solid (mg/l)	99.0 186.0	149.0	31.0- 162.0	81.5	99.0- 180.0	155.7	52.0- 116.0	88.2
	Percent Iron Removal average 99.6 in the range of 99.4 to 99.7 at a rate of flow of 0.72 $m^3/m^2/h$.				Percent Iron Removal averaged 98.1 in the range of 91.6 to 99.7 at a rate of flow of $0.66^3/m^2/h$.			

TESTING OF DEVELOPED SYSTEMS

Two of the systems were installed for operation in the field. These were MODIRU-1 and MODIRU-4. The objective of this activity was to test the effectiveness of each system and assess optimum conditions for operation.

Both units were installed at the Kuntanase Health Centre, the same place where the 'DIRU' was installed. The two units were operated under continuous flow conditions similar to those under which the 'DIRU' operated, as described under 'DIRU' above.

Both units were operated continuously for two hours on two days. The summary of the results is presented in Table 1.

As can be seen from the Table, the range of iron concentrations in the influent for both units was 13.0-18.0 mg/l. The highest effluent concentration recorded for MODIRU-1 was 0.09 mg/l while that of MODIRU-4 was 1.3 mg/l for the same influent concentration. The range of percentage iron removals was 99.4-99.7% for MODIRU-1.

All the effluent concentration from the MODIRU-1 unit (0.02-0.09 mg/l) were within the maximum permissible level set by WHO (1971 Standard). They were infact within the highest Desirable level of 0.1 mg/l. This shows that the unit was very effective in the removal of iron. The results from the MODIRU-4 show that but for one sample of effluent iron concentration which was 1.3 mg/l, all the other effluent concentrations (0.05-0.2) were within the maximum permissible level.

It may be noted that the effluent iron concentration of MODIRU-4 were generally higher than those from MODIRU-1. Thus the performance of MODIRU-1 in terms of efficient removal of iron appeared to be better than that of MODIRU-4 though it was expected that since MODIRU-4 is made up of two modules of MODIRU-1, it would perform better. But due to the limited nature of the data, no firm conclusion can be drawn from this.

CONCLUSION

It can be concluded from the national field survey that there was no clear relationship between the iron levels in boreholes and complaints from users. Nevertheless, most of the users were able to tolerate iron levels up to 4.0 mg/l.

Results from the testing of the developed systems, MODIRU-1 and MODIRU-4 indicate their great potential as iron removal units which can be used in rural areas in many developing countries where iron is a problem in groundwater supplies. However, there is the need for further studies and field testing of these promising units and the other modified systems, MODIRU-2 and MODIRU-3, and sponsorship is being sought for the purpose.

REFERENCE

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