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WATER, ENVIRONMENT AND MANAGEMENT

Simulation model of a water treatment plant

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ABSTRACT

Water treatment for large communities is an expensive venture involving substantial sums of capital outlay. Water treatment plant design attempts to create conditions favourable for physico-chemical processes of purification. However plant operators often realise, long after installation, that some of the unit processes require modifications to facilitate efficient operation. While these process modifications may require additional expenses, the most beneficial changes often result in substantial savings in operational costs. Therefore simulation study of model plants could be a useful tool in performance evaluation and in assessing the impact of any required modifications to existing full-scale treatment plants.

This paper report the results of a simulation model study of the Durban Heights Water Treatment Plant (DHWTP). A laboratory model of a typical water treatment plant was designed, constructed and installed at the University of Durban-Westville. Using the model to treat raw water from the Durban heights treatment plant intake, the performances of flocculation, coagulation, sedimentation, filtration and disinfection processes were evaluated based on results from routine analysis of samples of raw, post-sedimentation, pre-chlorination, and treated water. The results obtained were compared with data from the Durban heights water treatment plant and the paper concludes with useful recommendations that could enhance the efficiency of the treatment plant.

ABBREVIATIONS

DHWTP = Durban Heights Water Treatment Plant
TS = Total Solids
FC = Faecal Coliform

INTRODUCTION

The various unit processes in water treatment are often studied in isolation in most laboratory investigations. In the study reported in this paper an attempt is made to investigate the various processes of a model water treatment plant and to formulate a comparative analysis between a working model and a prototype water treatment plant.

The Durban Heights Water Treatment Plant (DHWTP) was selected for this comparative analysis because of its close proximity. It must, however, be pointed out from the on set that the laboratory model was not a direct replica of the plant. The objective of this study was not to develop a physical model of the DHWTP but instead to design, based on sound criteria, a portable laboratory model that could be a useful tool in the simulation of any typical water treatment plant. Suggestions or recommendations arising from such simulation studies could be helpful in improving the method of water purification.

The model water treatment plant

The laboratory scale model consisted the unit operations and components shown in Figure 1 below:

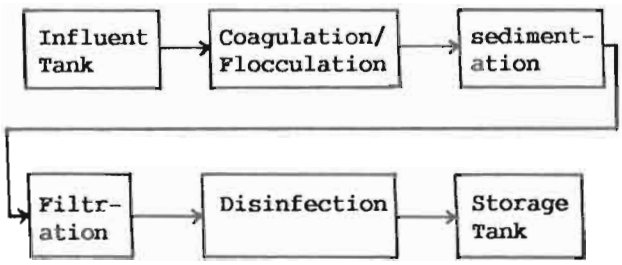

Fig 1 - Flow diagram of the model plant

The model was designed for a designed population of 130 people, based on a projected 10-year total population of the department of Civil Engineering at the University of Durban-Westville.

The required flow rate of 7540 l/day (or 7.54 m^3/day) for the model was determined based on a water demand rate (ref. 1) of 58 l/ capita/day (i.e. 5 litres for drinking, 46 litres for toilet flushing, and 7 litres wastage or loss in distribution). This flow rate was used in determining the capacities and dimensions of the various unit operations in the model as given below:

Coagulation Chamber:
- -Retention time of 30 seconds was assumed
- -Volume of chamber = 0.002604 m^3
- -A square chamber of dimensions, 13 cm x 13 cm x 15 cm was considered adequate for rapid mixing.

Flocculation Tank:
- -Assumed retention time = 1830 seconds (min. recommended ret. time in literature is 30 seconds (ref. 1))
- -Volume of tank = 0.15884 m^3
- -Based on a breadth-to-length ratio of 1:3 and a fixed depth of 0.3 m, the final dimensions of the flocculation tank were 1.35 m x 0.4 m x 0.3 m

(Note: The coagulation unit was constructed as a chamber within the flocculation tank just at the inlet to the tank).

Sedimentation Tank:
- -Assumed detention time = 15 minutes
- -Dimensions = 0.7 m x 0.4 m x 0.27 m

Filtration Unit:
- -Loading rate of 5 m^3/m^2/day was assumed
- -Cross sectional area unit = 1.5 m^2
- -Diameter of filter unit = 1.38 m

Because it was too expensive to construct a perspex filter column of this diameter an improvised filter column was used. An Armfield deep bed filter column is hoped to be installed for future investigations.

Filter Media:
- -Graded Umgeni sand was used.
- -Effective size of the sand was 0.26 mm
- -Recommended effective size of sand for slow sand filters in the literature (ref. 2) ranges from 0.2 to 0.4 mm.

Disinfection Unit:
- -Assumed detention time = 30 minutes
- -Volume of tank = 0.156 m^3
- -Dimensions = 1 m x 0.4 m x 0.4 m
- -Baffles were introduced in the tank at 140 mm spacing to facilitate good mixing.

Treatment processes at DHWTP

Figure 2 shows the flow diagram of the Durban Heights Water Treatment Plant. Raw water from Nagle dam is pumped via the Clermont pump station. Chlorine and activated carbon (when required) are added to the raw water at the inlet to the treatment plant. The pH of the raw water is maintained at about 8.8 with the addition of lime slurry and coagulation is carried out with the assistance of flash mixers, using polyelectrodes as coagulant.

After coagulation, the water moves under gravity to the pulsating settling tanks, and then to rapid gravity filters and finally to the disinfection tank. The plant uses chlorine gas as disinfectant and the treated water is stored in reservoirs to be slowly let out to meet the demand of the Durban area.

EXPERIMENTAL INVESTIGATIONS

Raw Water obtained from DHWTP is kept in the influent tank, from where it is fed into the flocculation tank via the coagulation chamber. In the chamber the raw water is dosed with 80 ml of 5g/l aluminium sulphate (Alum) solution at 30 minutes interval and rapid mixing occurs for approximately 30 to 60 seconds. In the flocculation tank, slow mixing is continued for about 30 minutes before the water passes under gravity flow into the sedimentation tank. Effluent from the sedimentation tank is pumped into the filter unit from where it flows by gravity into a baffled disinfection tank. Disinfection is achieved by the addition of 40 ml of 5g/l calcium hypochloride at 30 minutes interval.

Four sampling points were established in the process stream as follows:
Point A - for extraction of raw water before entering the coagulation chamber.
Point B - sampling of effluent from the sedimentation tank.
Point C - sampling of effluent from the filtration tank.
Point D - sampling of the final treated water (i.e. effluent from the disinfection tank.

Several experimental runs were performed using the model and for each run, samples

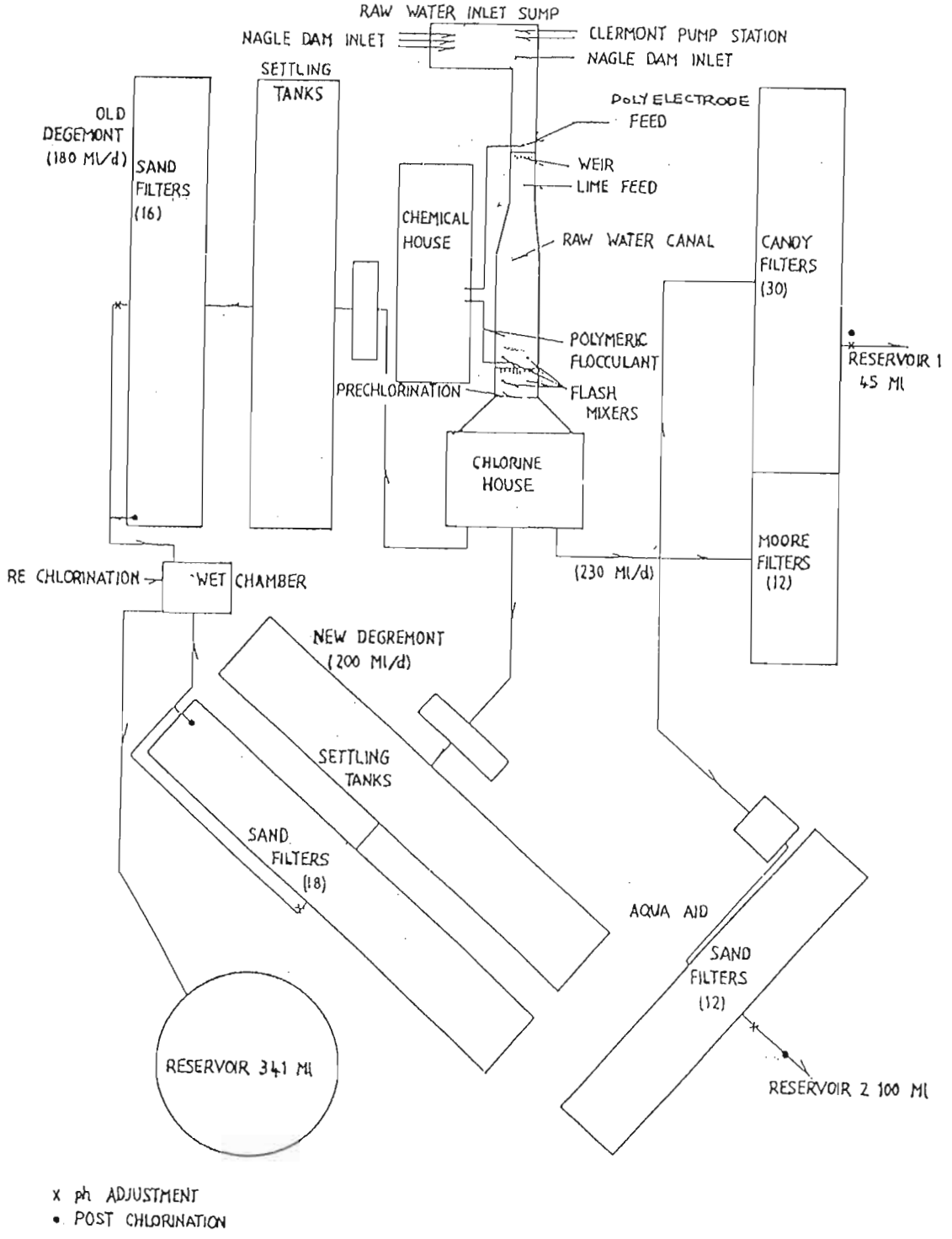

Fig 1 - Flow diagram of the DHWTP

were collected at the four sampling points. The samples were then analysed for alkalinity, turbidity, total solids (TS), pH, and faecal coliform (FC) in accordance with Standard Methods (ref. 3) for the Examination of Water and Wastewater.

RESULTS AND DISCUSSION

Table 1 gives the summary of the results obtained at the four sampling points. The overall performance of the model can be evaluated from the reductions of turbidity from 7.8 NTU in the raw water to 0.3 NTU in

the final treated water and faecal coliform from 11 per 100 ml of raw water to none in the treated water. The total solids data only gives a conservative estimate of the performance of the model as most of the solids removed in the sedimentation and filtration units are suspended solids. Based on the significant reduction in turbidity, it could be reasonably inferred that most of the total solids left in the treated water occur as dissolved solids.

Table 1 - Summary of results from the model

Parameters	Raw Water (A)	Sedimentation Tank Effluent (B)	Filtration unit Effluent (C)	Treated Water (D)
Alkalinity (mg/l)	27.0	27.4	27.0	27.2
pH	7.80	8.00	8.10	8.10
Turbidity (NTU)	7.80	4.40	0.40	0.30
TS (mg/l)	58.0	32.0	24.0	21.0
FC (per 100ml)	11	9	10	0

Differences between the model and DHWTP

In other to be able to put any comparison of the results of the model study with data from DHWTP into proper perspective, the major differences between the laboratory model and the operations at DHWTP should be highlighted.

(a) In the treatment plant, activated carbon is added to the raw water to remove any odour problems prior to coagulation. In the model on the other hand, no pre-chlorination or addition of activated carbon to the raw water was considered necessary.

(b) At DHWTP, polyelectrode is used to facilitate coagulation while in the model study alum is employed as the coagulant.

(c) Flocculation is achieved in the model using mechanical stirrers where as in the case of the treatment plant, flocculation is brought about by hydraulic turbulence.
(d) The model employed slow sand filtration while in the treatment plant rapid gravity filters are used.

In light of these differences, it would appear (see Table 2) that the results obtained from the model compared favourably well with data from the DHWTP.

Table 2 - Comparison of the results with data from DHWTP

	Model	DHWTP
Alkalinity (mg/l)		
Raw Water	27.0	26.6
Treated Water	27.2	26.9
pH		
Raw Water	7.80	7.70
Treated Water	8.10	8.00
Turbidity		
Raw Water	7.80	7.30
Treated Water	0.35	0.19
Total Solids (mg/l)		
Raw Water	58.0	66.4
Treated Water	21.0	60.0
Faecal Coliform (per 100ml)		
Raw Water	11	8
Treated Water	0	0

It would appear from the results of the study that the current practice of pre-chlorination of the raw water at the plant is unnecessary. There is also no justification for the use of polyelectrode for coagulation rather than the much cheaper alum. The current practice of achieving mixing through hydraulic turbulence in the plant is the much cheaper option and this needs to be simulated in future model study.

CONCLUSION

The most significant conclusion arising from the study is that the model produced treated water that meets the South African standards for drinking water.

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