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PERFORMANCE OF UPFLOW GRAVEL BED FLOCCULATOR

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TABLE OF CONTENTS

Page

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ABSTRACT

An investigation of the use of Upflow Gravel Bed Flocculator (UGBF) to flocculate colloidal particles caused by Kenya's laterite soil, i.e. red coffee soil, has been carried out. The theory part of the report has dealt with the basic theories of coagulation and flocculation. Basic literature on the subject has also been presented.

Experiments that have been conducted have tried to establish whether UGBF could be an economically viable alternative to the conventional coagulation-flocculation units. The efficiency of coagulation-flocculation has been assessed by determining effluent turbidity, floc quality and floc settlement properties.

It has been established that graded media is more efficient in UGBF than uniform media. It has further been established that graded media is especially good media for use in the UGBF with uniform cross-section. An UGBF run of 8½ hours was got when the flow through the cylindrical UGBF was 11,5 m/h. The level of turbidity varied between 126 and 400 NTU. For the case of tapering UGBF, it has been established that to get runs of adequate length, it is advisable to use media of sizes 6 - 13 mm throughout the bed. The flow should then be maintained between 9,0 and 14,4 m/h.

UGBF could find a lot of use for rural water supply schemes. For these water supplies economy is of the utmost importance. UGBF is a relatively cheap unit to construct and operate. Its operation and maintenance costs are also quite low compared to other conventional units. This unit requires only a head of 1,5 - 2 m. It would find application in any area where the raw water has some head. Topography of the area could also be used in order to give the extra head required for UGBF.

1 INTRODUCTION

With relatively few cases, nearly all surface waters have to undergo some kind of treatment before being distributed to the consumers. Contaminants originating from land erosion, dissolution of minerals and the decay of organic vegetation have always been present in surface waters and require removal in order to make the water potable. In addition biological pollutants may also be present. To remove these pollutants surface water needs to undergo the conventional treatment followed by disinfection.

Coagulation and flocculation followed by sedimentation is by far the most widely used process in the removal of substances which produce turbidity and colour in surface water. These substances consist largely of clay minerals, substances that produce colour and microscopic organisms. The particles occur in widely varying sizes ranging from those large ones to settle readily to small ones which can remain suspended in water for a very long time. Coagulation and flocculation are the processes to induce these tiny particles to come together and form heavier flocs which can then be removed by sedimentation.

The meaning of coagulation and flocculation in water and wastewater technology is as defined below.

> Coagulation is the process in which colloidal suspensions are destabilized and particles start to agglomerate.
>
> Flocculation is the process in which small particles are brought together by gentle stirring or agitation. This results in formation of larger particles of adequate size to settle with a velocity acceptable for separation. The term is also used to describe the growth process of the particles.

The design criteria for water treatment plants for less technically and economically developed communities should have

- maximum hygienic protection as expected for developed communities,
- minimum utilization of equipment since less developed communities tend to be importers rather than producers of equipment,
- maximum use of local materials and labour force within the region,

- slight or no automation since investment should generate employment opportunities and skilled maintenance is rarely available,
- optimum use of prime energy resources for construction and operation.

One water treatment process which fulfills the above requirements is the Upflow Gravel Bed Flocculator (UGBF) also known as the Sand Bed Flocculator. The UGBF provides a simple and inexpensive design for flocculation. It consists of a packed bed of gravel. This bed provides ideal conditions for the formation of compact settleable flocs. This is due to continuous recontacts of flocs provided by the sinuous flow of water through the interticides formed by the gravel.

Surface waters in Kenya are normally very turbid. These waters require intensive conventional treatment. The following study will endeavour to establish whether UGBF could be used to flocculate colloids caused by Kenyan latrite soil (red coffee soil). The study will also try to establish design parameters of UGBF. This will involve investigation of

- various designs of UGBF,
- the type of flocculator,
- the gravel bed media (grain sizes),
- design flows,
- performance of flocculator.

2 QUALITY OF SURFACE WATERS IN KENYA

Many of the rivers and streams in Kenya have turbid waters. Besides this pesticides have been detected in some surface waters. Most of these waters are very well aerated and can be used for water supplies after the ordinary methods of treatment. Typical average of the physical and chemical characteristics of river water in the humid areas of Kenya can be seen in table 1. The table was based on water quality study of Kenyan rivers made by the Government Chemist in 1962 to 1972.

Table 1. Physical and chemical characteristics of river water in the humid areas of Kenya (WHO 1972).

Parameter	Units or measure
Colour	Yellow-brown
Turbidity	100 JTU
pH	7,5
Total solids	100 mg/1
Total hardness	40 mg/1 as $CaCO_3$
Total alkalinity	55 mg/1 as $CaCO_3$
Iron	0,1 mg/1
Chloride	3 mg/1
Sulphate	7 mg/1
Fluoride	0,4 mg/1
Silica	25 mg/1

The characteristics of some river waters differ substantially from these average values. Rivers arising from the Tenderet area east of Kisumu contain more than twice as much hardness, alkalinity and total solids. Rivers in the Aberdares region contain half of the above values of hardness, alkalinity and total solids (WHO 1972).

Lake waters in Kenya range in quality from that of the streams feeding the lake to brackish conditions that result from the evaporation of water from lakes having no outlet with the resultant build up of salt concentration. In general the lakes have low turbidity waters but the high dissolved solids concentration in some of the lakes render them unsuitable for public water supply (WHO 1972).

3 THEORY OF COAGULATION

3.1 Stability and instability forces

The terms stability and instability of colloids refer to the inherent property of colloidal particles to remain dispersed and tendency of particles to coalesce respectively. The forces exerted on colloidal particles in a solution can be seen in figure 1.

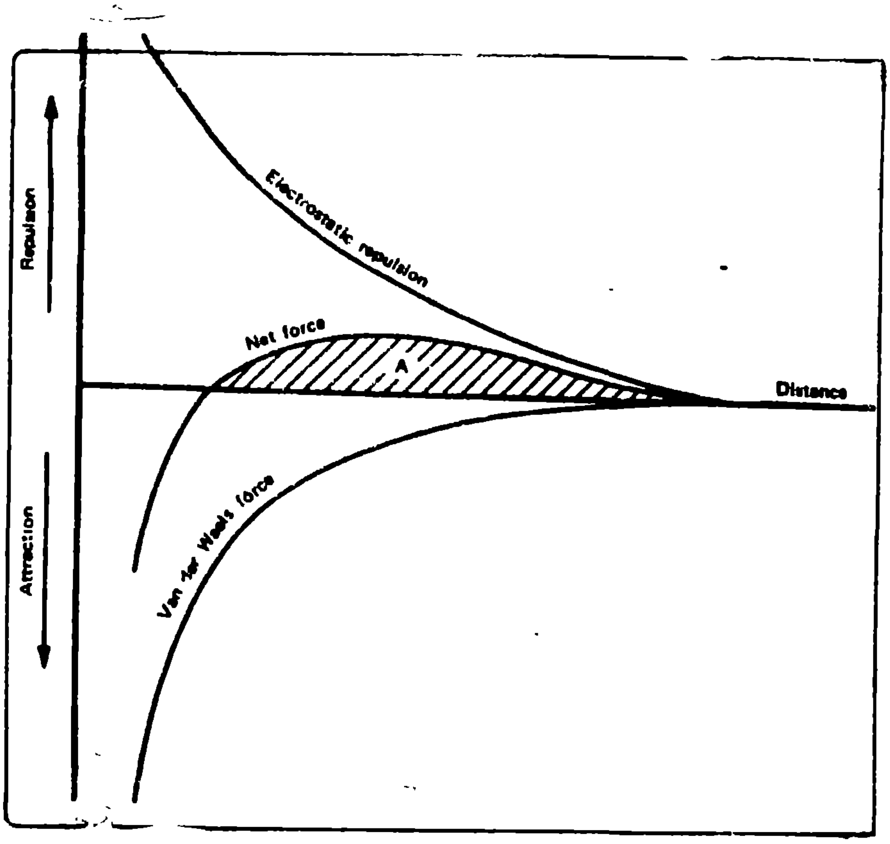


Figure 1. Forces between charged colloidal particles (Barnes et al 1983).

Coagulation process acts to destabilize particles resulting in formation of aggregates. For hydrophilic colloidal system stability is maintained by a phenomenon of hydration as can be seen in figure 2. Water molecules are attracted to the surface of the particles and act as a barrier to contact between particles (Barnes et al 1983).

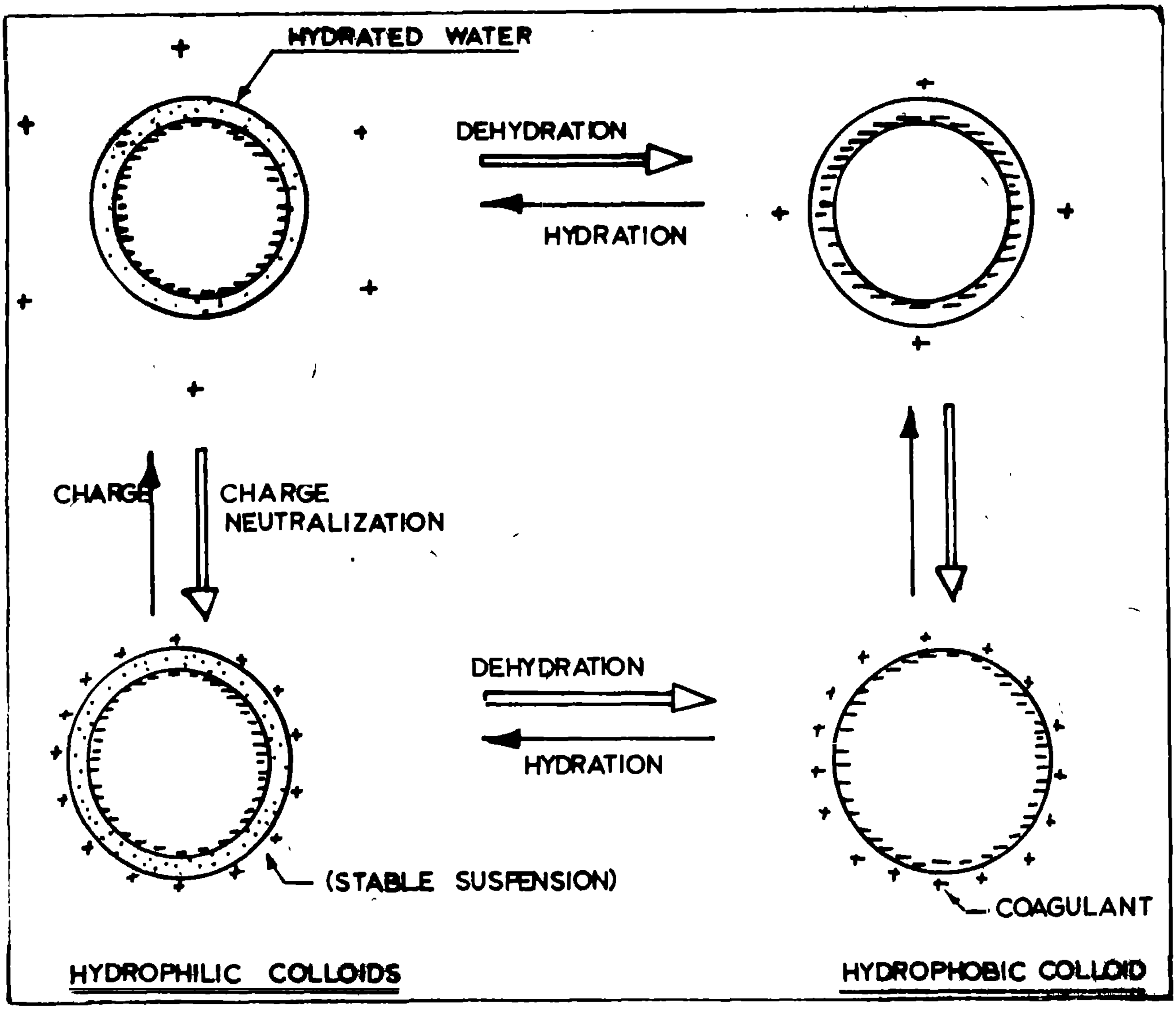


Figure 2. Schematic representation of hydrophilic and hydrophobic colloids (Japanese International Cooperation Agency JICA 1975).

Stability of hydrophobic particles is due to an electrical double layer consisting of the charged particle surface and a surrounding sheath of ions with opposing charge to that of the particle surface. For particles in natural waters the charge is usually negative. These electrical charges may arise through ionization of atoms at the particle surface or replacement of elements in a crystal lattice by elements having a different charge. Particles may acquire the charge through adsorption of ions particularly hydroxide ions from the water itself. These ions are tightly bound to the surface of the particle and attract ions of opposite charge from a mixture of positive and negative ions in the water. This layer of oppositely charged ions called counterions is held near the particle by the electrostatic forces. Thermal agitation of the water molecules causes the counterions to form a diffuse layer extending out from the particle surface into the bulk of solutions as shown in figure 3. The potential decays exponentially from the particle surface and eventually becomes zero where equal concentrations of cations and anions are present (AWWA 1971).

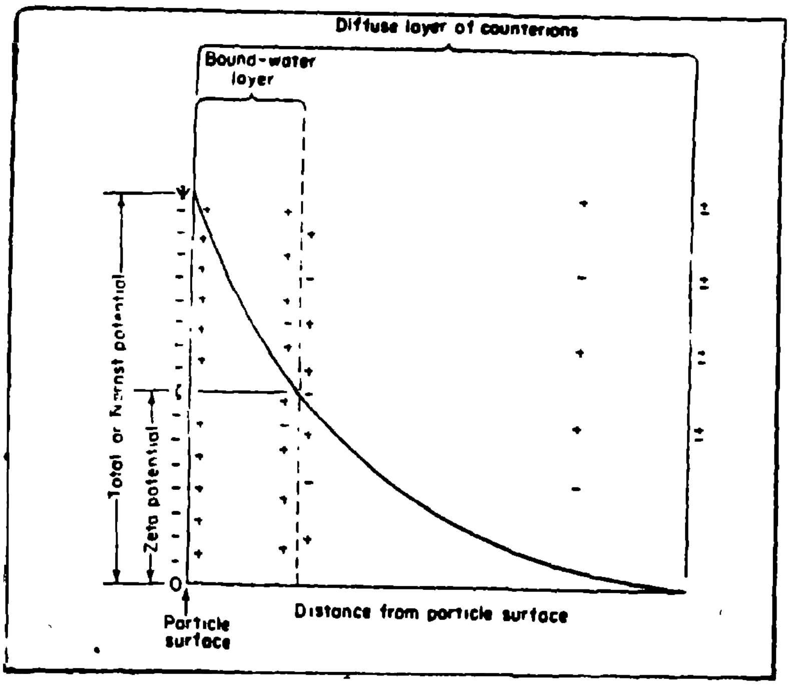


Figure 3. Structure of a double layer and the corresponding potentials. ψ is at the particle surface, and ζ is at the hydrodynamic plane of shear (AWWA 1971).

The double electrical layer surrounding each particle in the water then results in regions of electrical potential in a bulk solution that has a zero potential. The electrostatic work required to transport a unit charge from this bulk solution through the phase boundaries of each layer surrounding a particle to any point measures the potential at that point. The potential at the surface of a particle is called "total potential" or Nernst potential (ψ) (AWWA 1971).

There is a second potential called "zeta potential" (ζ). It is located at the "plane of shear" at the boundary between solvent adhering to the particle in its motion and that which moves with respect to it. This "plane of shear" separates the water of hydration from free water (AWWA 1971).

Zeta potential gives a measure of particle stability. The existence of electrical double layers around particles inhibits the close approach of particles to each other and thereby makes the suspension very stable. Double layer potential and surface charge density are sensitive to concentration and valence of ions in solution. Stability can be adversely affected by addition of suitable ions to the solution (AWWA 1971).

Instability forces act in opposite direction to stabilization forces. The particles become destabilized or coagulated. One of these forces is Brownian movement. In study of colloidal systems it was found that small particles of diameters 100μm or less were in constant motion. The motion energy is obtained from collisions with water molecules. This energy increases with increase in temperature. Brownian movement results in collisions of particles and unions may result. These unions may not be everlasting unless the particles had already been destabilized. Brownian movement does not have much effect on large particles. The best way of improving collisions is by provision of hydraulic gradients by mixing or by creating areas of turbulence (AWWA 1971).

Another force also at play in water which causes instability is the attraction between particles. This force is called the van der Waals force. If the electrical forces of repulsion between particles is sufficiently reduced to permit particle to particle contact, the particles may stick to each other leading to progressive agglomeration.

3.2 Colloidal chemistry

Addition of electrolytes can cause colloidal solution to coagulate at relatively high concentrations. Schultze-Hardy's rules of coagulation (AWWA 1971) state that

1) coagulation is caused by ions having charge opposite to that of the colloidal particles,
2) coagulating power of an ion is markedly dependent on ito valency. Thus, a bivalent ion is approximately 30 to 60 times more effective than a monovalent ion and a trivalent ion is 700 to 1000 times more effective than a monovalent ion.

Schultze and Hardy also showed (AWWA 1971) that stability of colloids was due to repulsion forces between particles and introduction of oppositely charged ions resulted in charge neutralization with consequent zeta potential reduction to zero. As a result coagulation then occurred.

Colour removal in water is a sort of chemical precipitation rather than coagulation. The coagulants (for example aluminium salts) and acidic group on the colour molecule interact forming an insoluble basic salt. These salts are insoluble in water and cause precipitation removing from the solution both colour and coagulant compounds.

Coagulation is also used in water softening by precipitation.

3.3 Metal coagulants

The most frequently used metal coagulants are aluminium and ferric salts.

When aluminium salt is added to the water, a series of reactions occur with water or with other ions in the water. The process is called hydrolysis. Aluminium ions form a series of multivalent charged hydrous oxide species in water. Depending on the pH of water these compounds may range from positively charged ions at lower pH values to negatively charged at the more basic pH values. Recent evidence has indicated that aluminium ions bridged by two hydroxyl ions result in a more effective coagulation group of ions (AWWA 1971).

Ferric salts undergo a similar series of hydrolysis.

3.4 Factors influencing coagulation

3.4.1 pH

For any particular water there is a particular pH range where coagulation and flocculation occur in the shortest time for a given coagulant dose. The pH range for hydrolysis of aluminium salts is 5,5 to 7,8. In turbid water containing ions the pH range is generally 6,0 to 7,8 (AWWA 1971).

The pH zone of iron coagulation is generally broader (see figure 4). The interrelations between pH and coagulant dosage which is necessary for coagulation of colloidal particles in water of clay origin can be seen in figure 4.

For the removal of colour the best operating pH is in the range of 4 to 6. The dosage of coagulant depends on the initial amount of colour (AWWA 1971).

The relationship between pH, alum dosage, colour removal and zeta potential (expressed as mobility) is shown in figure 5.

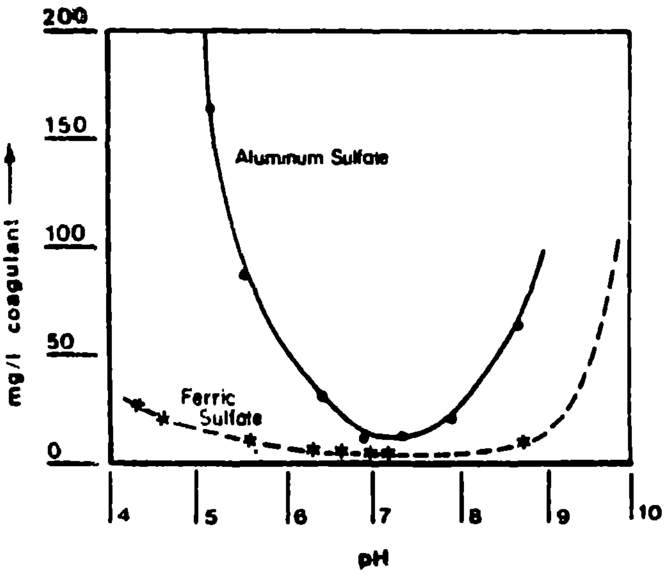


Figure 4. pH zone - coagulation relationship. Coagulation of 50 mg/l kaolin with aluminium sulphate and ferric sulphate (AWWA 1971).

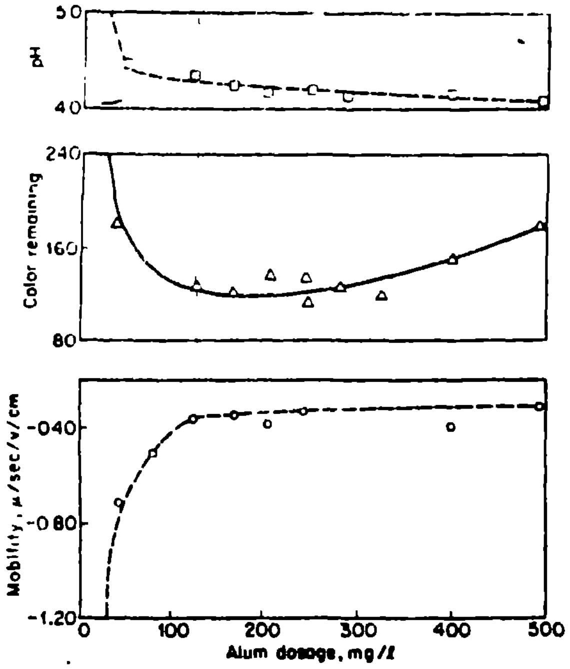


Figure 5. Effect of alum dosage on coagulation of coloured water. Curves show the effect of alum dosage on floc mobility, colour removal and pH. Colour removal was poor with all dosages. The best sample showing a residual colour of 120 units (AWWA 1971).

3.4.2 Salts

The presence of some salts in water may affect
1) the pH range of optimum coagulation,
2) the time for coagulation,
3) the optimum coagulant dose,
4) the residual coagulant.

Experiments conducted on effect of ion on coagulation have led to the following conclusions (Weber 1977).

- Coagulation by the help of aluminium or iron salts is subject to greater interference from anions than from cations.
- Anions extend the optimum pH range for a coagulant to the acid side in proportion to their valency.

3.4.3 Nature of turbidity

Some generalized effect of nature of turbidity is as indicated below (AWWA 1971).

- A certain minimum amount of coagulant must be added for any clay turbidity.
- Some additional coagulant is generally required with increase in turbidity.
- For very high turbidities relatively smaller coagulant doses are required because of the high collision probabilities and vice versa.
- Adsorbent organic matter on clays from natural streams does not increase coagulant demand.
- A broader distribution of clay particle sizes is much easier to coagulate than a suspension containing a single or narrow range of particle sizes.

3.4.4 Coagulant

Alum is the most common coagulant. Iron salts can be used as well and in some instances they have advantages over alum. An important advantage of iron salts over aluminium salts is the broader pH range for good coagulation. This phenomenon can be better explained in figure 4.

3.4.5 Physical factors

Temperature seems to have some effect on coagulation. Coagulation becomes difficult as temperature approaches 0 ^{o}C. The optimum coagulation pH decreases with increase in temperature.

Difficulties arising from cold temperatures can be overcome by conducting coagulation as near as possible to the optimum pH for that type of water at that temperature (AWWA 1971).

3.4.6 Presence of nuclei

Number of particles affects the rate of coagulation and contributes to increased density of floc and hence increased settling velocities. A small number of particles contributes to low rate of floc formation and settling characteristics of the flocs (AWWA 1971).

3.4.7 Effect of mixing

Two stages of mixing are generally used in a water treatment plant. Rapid mixing is done to distribute the coagulant throughout the water being treated. This is referred to as flash mixing. Flash mixing should continue for 30 to 60 seconds (Barnes et al 1983). This allows for hydrolysis of the coagulant.

Gentle stirring during the second stage of flocculation promotes floc growth. Detention time is 10 minutes but more frequently 30 to 60 minutes are generally adequate to produce a floc that will settle in a reasonable time (AWWA 1971).

For conventional systems the mixing could be achieved through the use of hydraulic rapid mixing or mechanical rapid mixing.

3.4.8 Optimum coagulant dose

The factor to be optimised is made up of two main components, that is cost and performance. The optimum dose is then the least cost dose which will produce a readily settleable floc. This way turbidity is removed efficiently in a reasonably short time. Also excess colour is removed. Besides water gets better filterability properties because the relatively small flocs which could not settle in sedimentation basin are retained in filtration unit.

Methods which can be used for determination of the optimum coagulant dosage are jar test method and zeta potential method. Out of these two methods, the jar test is commonly used, because of its simplicity.

3.4.9 Coagulant and flocculant aids

In some waters coagulation is poor even with the best dose of a coagulant. Some problems experienced include small and slowly settling flocs as well as fragile flocs that are fragmented under hydraulic forces. There is also inability to obtain clarification in presence of interfering substances (JICA 1975).

Sometimes an improvement in coagulation and consequently, in settling is desired. This may be necessary during peak loads in excess of the original design or there may be a reduction in the size of the original construction.

The addition of substances known as coagulant aids can often result in considerable improvement in coagulation and an increase in the settling velocity of the resulting flocs. This phenomenon can clearly be seen in figure 6.

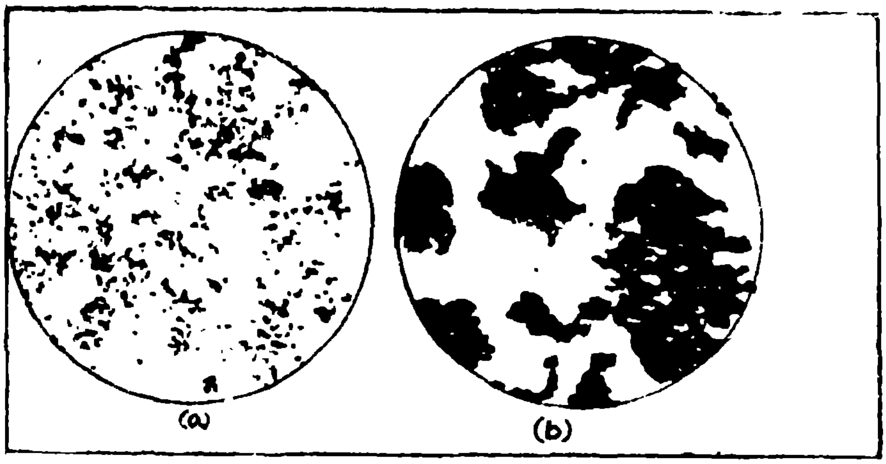


Figure 6. Photomicrograph of alum floc with and without polyelectrolyte aid.
(a) Without, (b) with polyelectrolyte (AWWA 1971).

Some of the best known coagulant aids are
1) clay,
2) polyelectrolytes,
3) activated silica,
4) oxidants (e.g. ozone),
5) natural coagulants (e.g. sodium alginate).

4 FLOCCULATION

4.1 Why flocculation is needed

Flocculation allows particles to grow. The resultant flocs have better settleability and filterability properties.

When a colloidal has been destabilized the growth of flocs due to the agglomeration of the colloidal particles occurs mainly in two stages known as perikinetic and orthokinetic flocculation. There is a third type of flocculation which occurs due to differential settlement of particles (Chin-Chi 1982).

4.2 Flocculation process

4.2.1 Perikinetic flocculation

During this stage of flocculation, particles come into contact due to random Brownian motion of particles. The time taken for particles to grow so large that they are no longer significantly affected by Brownian motion depends on the frequency of collisions. The opportunity of particles to collide with each other depends on the concentration of particles.

The time taken for effective completion of perikinetic phase of flocculation is usually less than a minute (Barnes et al 1983).

The rate of change of the total concentration of particles due to perikinetic flocculation may be presented as follows:

$$J = \frac{dn}{dt} = \frac{4\eta}{3\mu} \cdot kTn^2 \qquad (1)$$

J = rate of perikinetic flocculation

n = total concentration of particles in suspension per unit volume at time t

η = collision efficiency factor

k = Boltzman's constant

T = absolute temperature (^{o}K)

μ = fluid viscosity (Ns/m)

(Chin-Chi 1982).

4.2.2 Orthokinetic flocculation

After flocs become aggregated to bigger particles during perikinetic flocculation the Brownian movement stops being so effective in making particles to collide. Further flocculation requires transport of particles by energy from outside. This stage of flocculation is called orthokinetic flocculation.

Under laminar flow conditions, the rate of change in total concentration of particles having a uniform particle size with time J_{Lam}, may be described by the following equation (Chin-Chi 1982).

$$J_{Lam} = \frac{4}{3}\frac{du}{dy} D^3 n^2 \qquad (2)$$

J_{Lam} = rate of flocculation during laminar flow
D = diameter of the colloidal particles
$\frac{du}{dy}$ = velocity gradient G (s^{-1})
n = total concentration of particles in suspension in number per unit volume at time t

The head loss through an incompressible porous media at the flow rates used for water filtration can be considered to follow the relationship established for laminar flow in a capillary. Darcy investigated this flow in 1830 and later Kozeny studied this flow further.

$$V = K_D \frac{\Delta p}{L} \qquad \text{(Darcy's Law)} \qquad (3)$$

V = approach velocity (m/s)
Δp = drop in hydraulic pressure (m)
K_D = constant depending on physical properties of the bed
L = thickness of the bed (m)

The above formula can be rewritten using Hagen-Poiseuille formula for flow in capillary to give the form developed by Kozeny.

$$\frac{dH}{dL} = \frac{K \; v \; (1 - f)^2}{\rho g \; f^3} \cdot {\frac{S}{V}}^{2} \qquad (4)$$

$\frac{dH}{dL}$ = head loss per unit depth of media (m/m)

μ = dynamic viscosity (Ns/m^2)

ρ = density of fluid (kg/m^3)

f = porosity (%)

$\frac{S}{V}$ = surface area to volume ratio of grains (m^2/m^3)

K = Kozeny's constant $\approx$ 5

(Willson et al 1980).

The following improved Kozeny's formula will be used for the study of performance of Upflow Gravel Bed Flocculators.

$$h = \frac{f}{\theta}\left(\frac{1-\alpha}{\alpha^3}\right)\frac{L}{d}\cdot\frac{v^2}{g} \qquad \text{(Carmen-Kozeny formula)} \qquad (5)$$

$$f = 150\,\frac{(1-\alpha)}{R_N} + 1{,}75$$

$$R_N = \frac{dvP}{\mu}$$

h = head loss (m)

α = porosity

L = depth of gravel bed (m)

v = face velocity (m/s)

θ = shape factor ($\approx$ 0,8)

d = average size of gravel (m)

g = gravity constant (9,81 m/s^{-2})

R_N = Reynold's number

ρ = specific gravity of water (kg/m^3)

μ = dynamic viscosity (Ns/m)

After calculation of head loss in the U.G.B.F., the velocity gradient G in the flocculator can be calculated using the formula shown below.

$$G = \sqrt{\frac{h\rho g Q}{\mu\alpha V}} \qquad (6)$$

G = velocity gradient (s^{-1})

h = head loss (m)

ρ = density of water (kg/m^3)

g = gravity constant (9,81 m/s^{-2})

Q = discharge (m^3/s)
μ = dynamic viscosity (Ns/m^2)
α = porosity of the gravel
V = volume of gravel bed (m^3)

If the detention time in the flocculation is t(s) then the product of G and t gives a dimensionless number called Camp number. Good flocs can only form when the Camp number is within some range.

4.2.3 Differential settlement

A third type of flocculation occurs where there are particles of varying sizes present. The varying sizes of particles result in the larger particles settling faster than the smaller ones.

The motion of the larger particles can also cause local velocity gradients which could be effective in speeding up orthokinetic flocculation of very small particles in their vicinity (AWWA 1971).

4.2.4 G and t values in flocculation

The optimum values of shear gradient (G) and the flocculation time (t) depend on the chemical composition of the water as well as nature and amount of colloidal particles present. The optimum value of G tends to decrease with increasing turbidity. Mean G values of between 20 to 100 s^{-1} and flocculation times of 20 to 40 minutes are commonly used for the conventional flocculation units (Barnes et al 1983).

For any raw water, there are some optimum values of G and t and a range of G and t values which give adequate performance of flocculation as shown in figure 7.

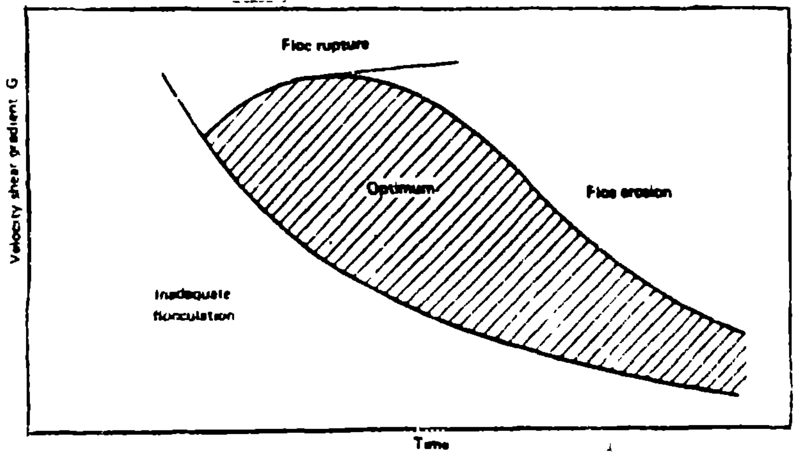


Figure 7. Typical zones in G-t plane.(Barnes et al 1983).

The product of G and t results in a dimensionless number which can be used to judge the adequacy of flocculation. This number called Camp number should vary between 2 x 10^4 to 2 x 10^5 if adequate flocculation is to be expected in conventional flocculation units (Barnes et al 1983).

Flocculation time can be reduced considerably by using gravel bed media because the entire bed is effective in the formation of sizable flocs and there is very little short circuiting. From 3 to 5 minutes flocculation time in the gravel bed media is equivalent to 15 minutes in the jars under laboratory conditions (Schulz et al 1984). The flocculation is equal to 25 minutes flocculation time in non-compartmented plant flocculation basin. When the corresponding flocculation times were used for the gravel bed, the laboratory flocculation and full scale flocculator the following results were obtained (figure 8) (Schulz et al 1984).

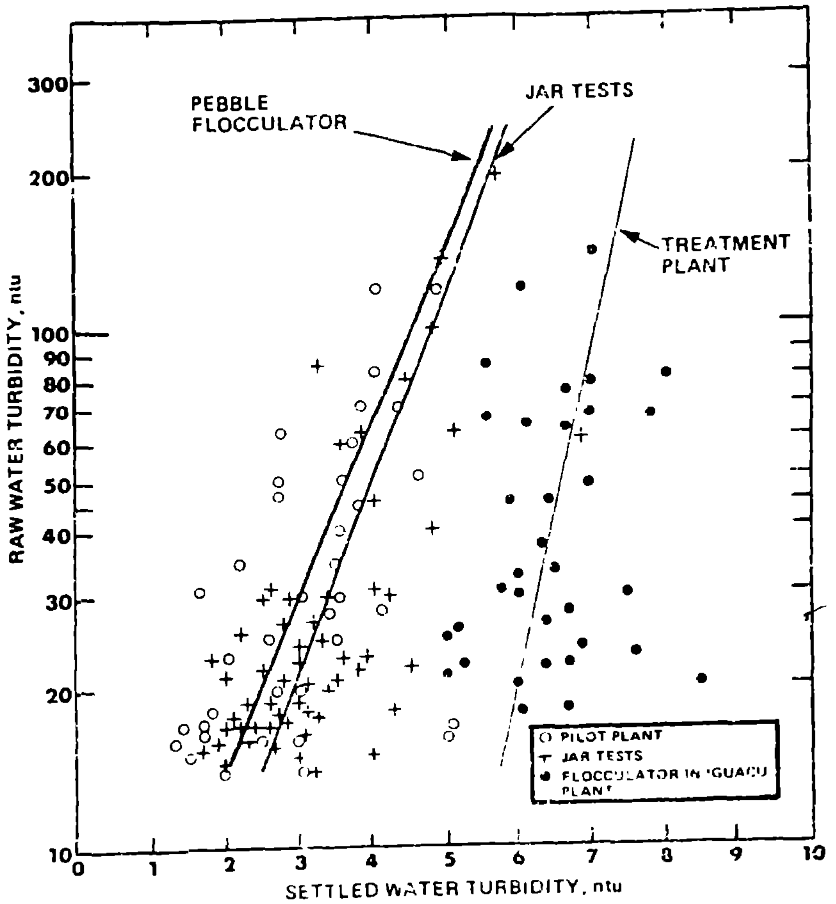


Figure 8. Comparison of results of gravel bed (pebble) flocculation in the pilot plant with results of jar tests with the full scale plant flocculator at the Iguacu plant in Curitiba, Brazil (adapted from Richter 1981 by Schulz et al 1984).

Initial floc formation is proportional to velocity shear gradients, high-velocity shear gradients can cause large flocs to be ripped apart as a result of either internal tension or surface shear stress erosion or both.

Figure 9 shows the velocities at the upper and lower edges of a particle relative to the centre of the particle. The tangential velocity of magnitude Gd/2 produces a couple which will tend to make the particle rotate with a peripheral velocity of the order of Gd/4. This induces additional shear stresses at both the leading and trailing edges of the particle (Barnes et al 1983).

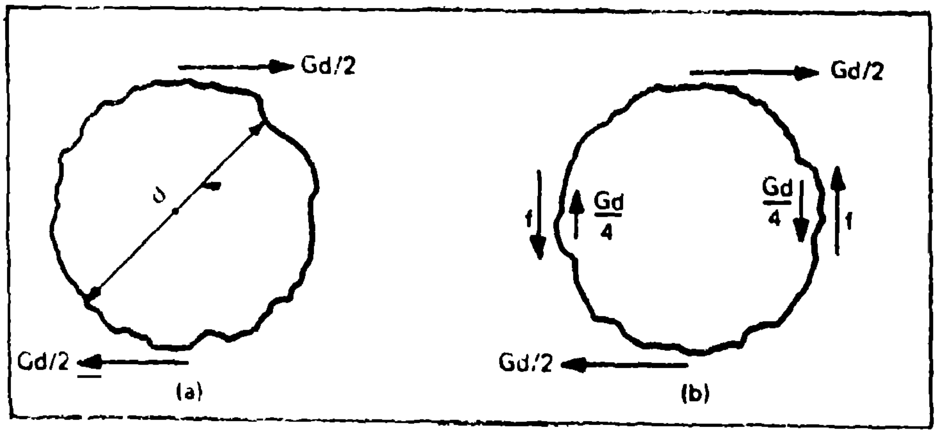


Figure 9. Possible floc rupture mechanism (Barnes et al 1983).

When the principal tensile stresses induced by the shear forces on the particle exceeds the tensile floc strength the particles will break apart. The tensile stress is proportional to Gd and the floc tensile strength (U) is a function of the properties of the colloidal particles and other matter which have come together to form the floc. The value of U can also be a function of floc size. As long as θ Gd $\leq$ U (θ is proportionality constant depending on water temperature and particle shape), the floc does not rupture but when θ Gd > U, floc rupture will occur (Barnes et al 1983).

The rate of particle growth (dN/dt) can be accelerated by having large values of G. The particles grow in size as G increases. However, a certain size of particle and value of G is attained beyond which the flocs start to rupture (Barnes et al 1983).

4.3 Flocculators

4.3.1 Mechanical flocculators

As has been discussed earlier during orthokinetic flocculation, it is necessary to introduce energy into the water to create velocity gradients. This is necessary if further flocculation has to continue. Any introduction of this sort of energy mechanically results in a mechanical flocculator.

Below are listed some of the well known mechanical flocculators:

1) pneumatic mixing and stirring flocculators,
2) paddle and reel flocculators,
3) turbine flocculators.

4.3.2 Hydraulic flocculators

In this case shear velocity gradients are achieved by dissipation of energy as water flows through a channel with fixed baffles. Another way is to dissipate energy by passing water through capillaries in the gravel media.

This latter process is mainly used in upflow gravel bed flocculator. The power input and the G value can be calculated as shown below (Weber 1977).

$$P = Q\rho gh \qquad (7)$$

$$G = \sqrt{\frac{P}{\mu V}} \qquad (8)$$

P = power input (kW)
μ = kinematic viscosity of water (Ns/m^2)
V = volume available for flocculation purpose (m^3)
Q = discharge (m^3/s)
h = head loss as the water flows (m)
ρ = density of water (kg/m^3)

The gravel bed flocculator provides a simple and inexpensive solution for flocculation in small water treatment plants where capacity is less than 5000 m^3/d (Schulz et al 1984). The packed gravel provides ideal conditions for the formation of compact settleable flocs, because of continuous recontacts provided by the sinuous flow of water through the interstices formed by the gravel media. The velocity gradients that are introduced into the bed are a function of

1) the the size of the gravel,
2) rate of flow,
3) cross sectional area of the bed,
4) head loss across the bed (Schulz et al 1984).

There are several types of gravel bed flocculators depending on direction of flow and shape. These are a downflow gravel bed flocculator (figure 10) and a upflow gravel bed flocculator (figures 11 and 12).

Tapered velocity gradients are achieved in gravel bed flocculators by changing the cross sectional area of the bed. This could also be achieved by grading the bed with different sized layers of gravel (Schulz et al 1984).

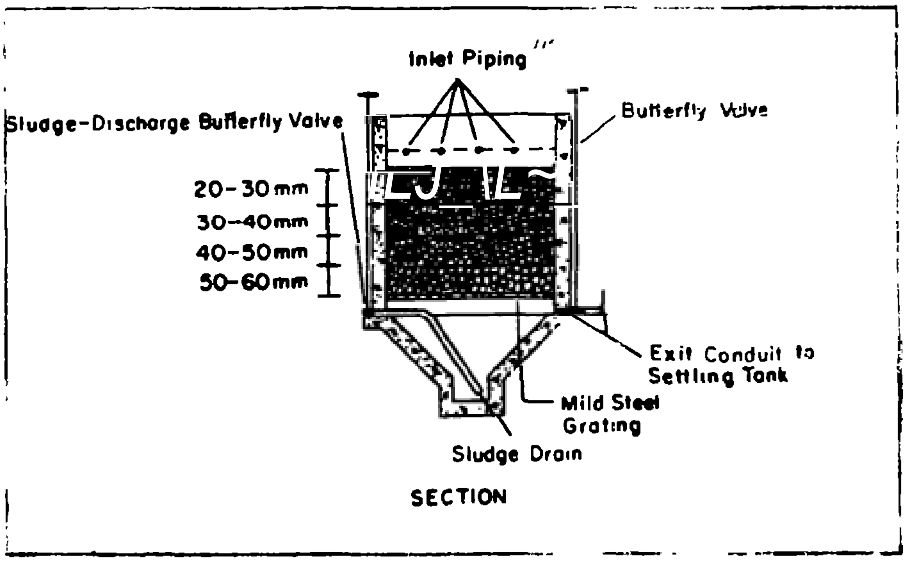


Figure 10. Downward flow gravel bed flocculator (Schulz et al 1984).

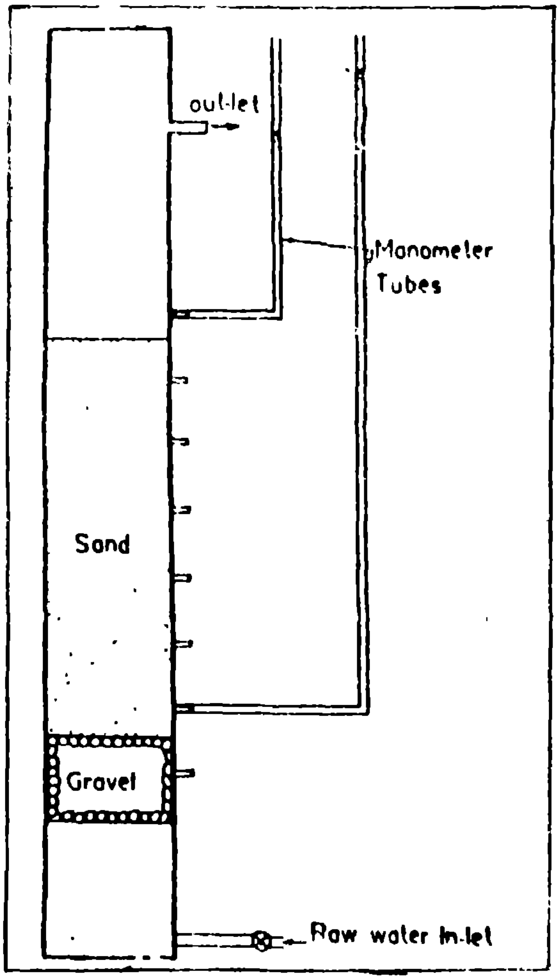


Figure 11. Sand media flocculator unit (Bhole et al 1977).

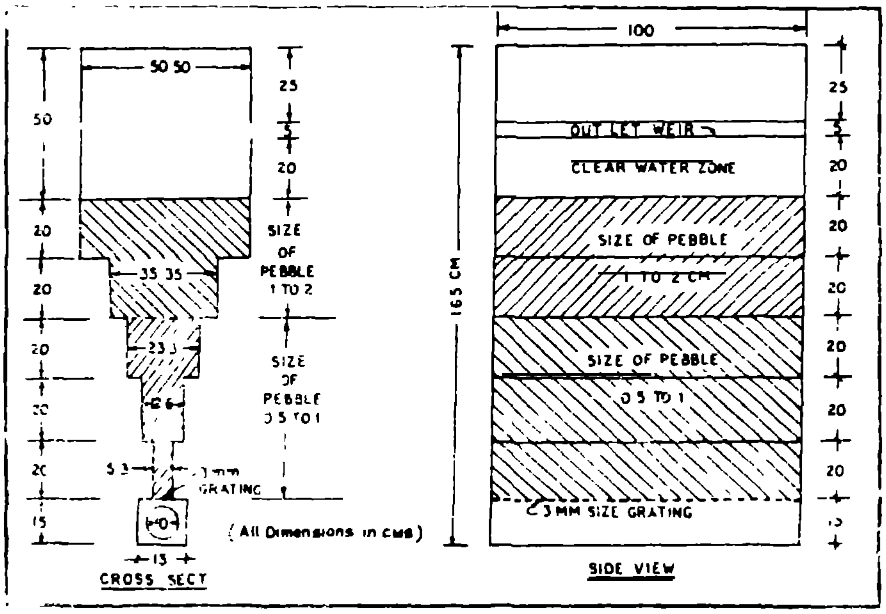


Figure 12. Upflow gravel bed flocculator (Schulz et al 1984).

5 EXPERIMENTAL INVESTIGATIONS

5.1 Objectives of experimental investigations

The study will endeavour to establish whether UGBF could be used to flocculate colloidal particles caused by Kenyan laterite soil (red coffee soil).

The investigation will also try to establish the suitability of the flocculation column as a replacement of the conventional coagulation-flocculation units. The characteristics of flocs will also be investigated.

Investigations were conducted on possibility of the use of UGBF in case where one had varying magnitude of suspended solids.

5.2 Scope of investigation

The variables which were selected for investigation were
a) various designs of UGBF,
b) the gravel bed media (grain sizes),
c) design flows.

To check on the characteristics of flocs several methods were used.
1) Imhoff cone was used to check on settleability property and amount of settleable solids in the effluent;
2) In flock comparator the appearance, size and quantity of flock is compared to a floc-size chart in figure 13.

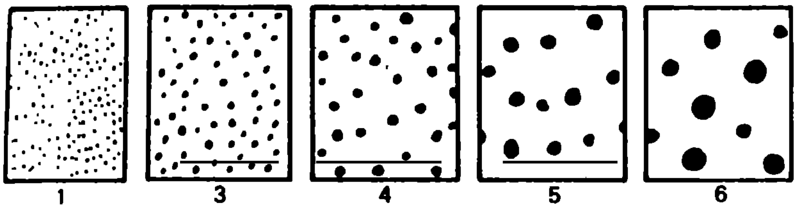


Figure 13. A typical floc comparator (Barnes et al 1983).

The Imhoff cone was also used to measure the amount of suspended solids in the raw water.

5.3 Pilot plant design and fabrication

5.3.1 Galvanized iron (GS) plate cylindrical UGBF

The unit was fabricated out of 18 gauge (British standard) GS plate. A schematic figure 14 of the unit has been placed in the report. The unit was fabricated by welding two pieces at the level where perforated plate is situated. The unit can also be seen in experimental set up in figure 15.

5.3.2 GS plate tapering UGBF

This unit can be seen in figure 16. The unit was designed to give G values ranging from 692 s^{-1} at the inlet and 28 s^{-1} at the top. Two gravel sizes were used, that is from 5 to 10 mm and from 10 to 20 mm. The design calculations can be seen in appendix 1. The unit was designed to handle a flow of 9 m^3/day.

The unit was fabricated out of a GS plate. The open corners were welded together. Inlet pipe, outlet pipes and manometric pipes were also welded at the convenient points. The unit can be seen when mounted in the whole experimental set up in figure 17.

5.3.3 Unit for synthesizing raw water

This unit consisted of a stirrer made from a 0,373 kW motor and a 220 l drum. The stirrer was mounted on to the drum as can be seen in figures 15 and 17. An overflow and an outlet pipe were also welded on to the drum.

5.3.4 Perspex tapering UGBF

This unit was fabricated out of pieces of perspex sheet cut from a 6 mm thick sheet (figures 17, 18 and 19). This was an improvement on the tapering GS UGBF. A suspended solids (SS) chamber was introduced at the inlet side. Chloroform and another glue bearing a trade name of Arodite were used for gluing the pieces together. The area of the unit was 0,05 x 0,05 m^2 and 0,2 x 0,2 m at the bottom side and top respectively.

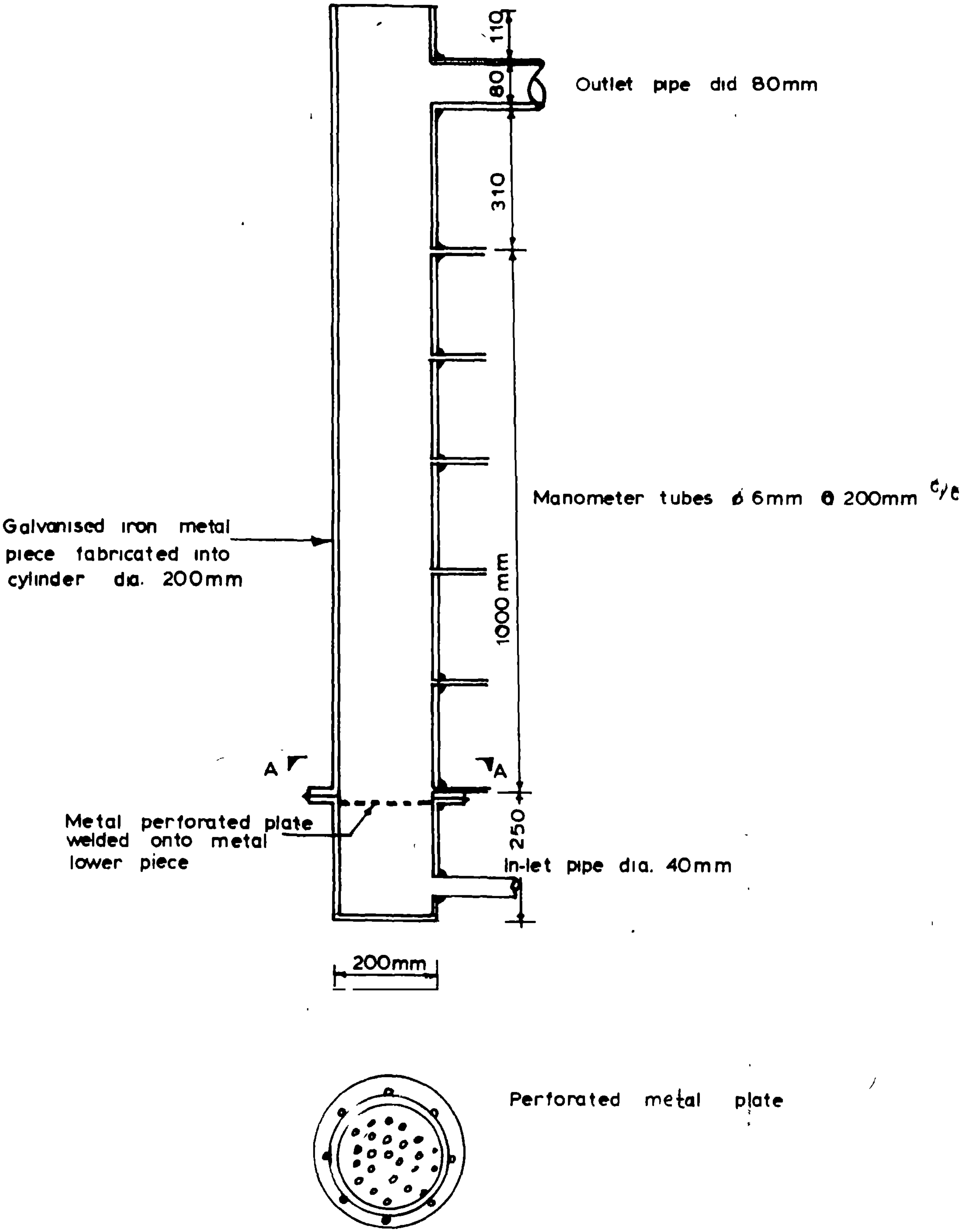


Figure 14. Cylindrical upflow gravel bed flocculator.

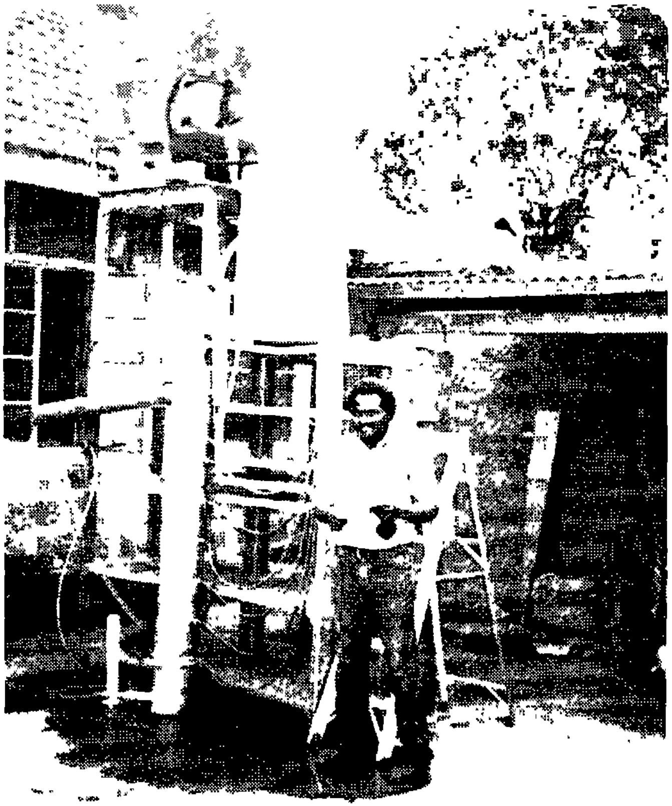


Figure 15. GS plate cylindrical UGBF unit in the experimental set up.

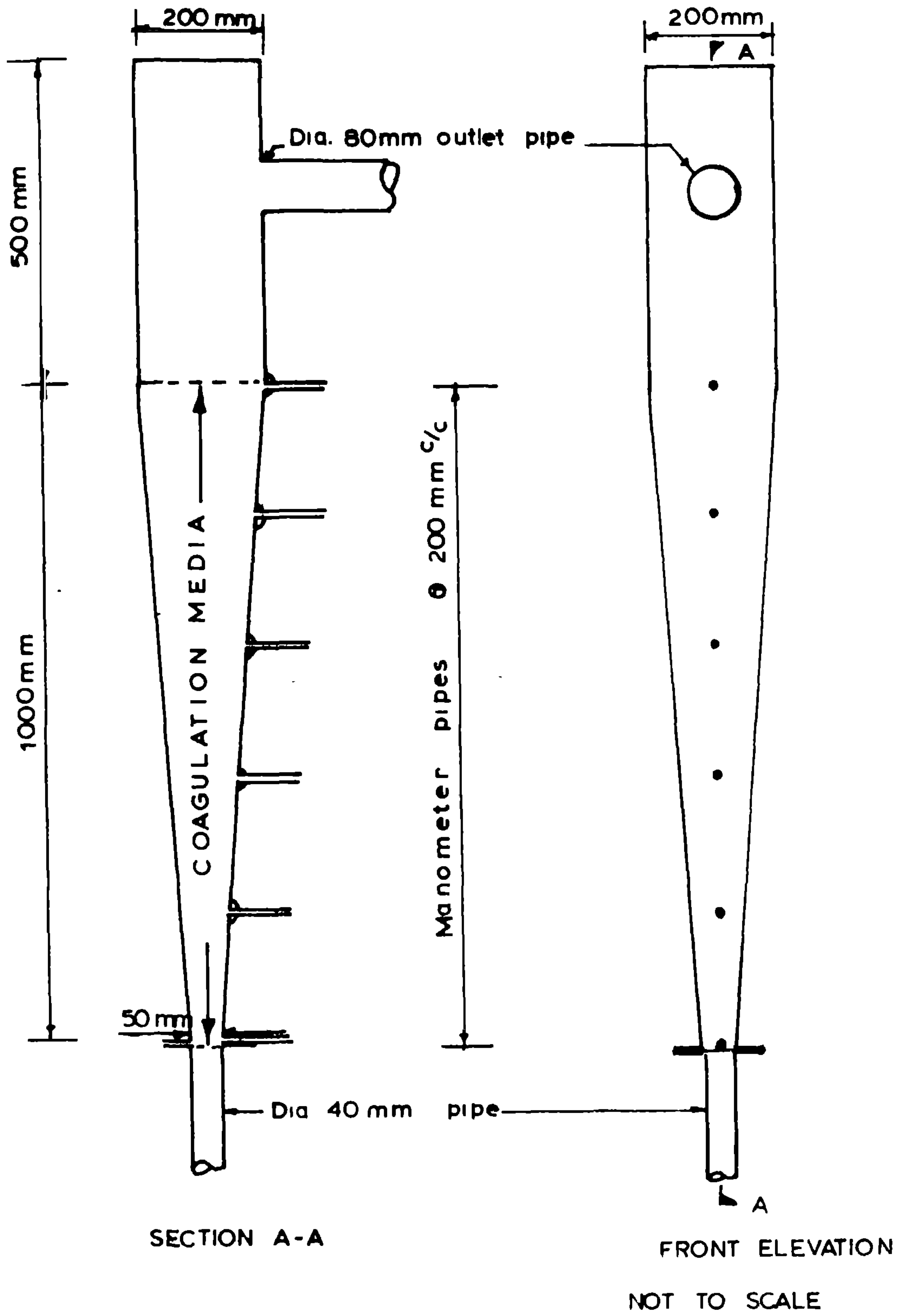


Figure 16. Tapering upflow gravel bed flocculator pilot plant.

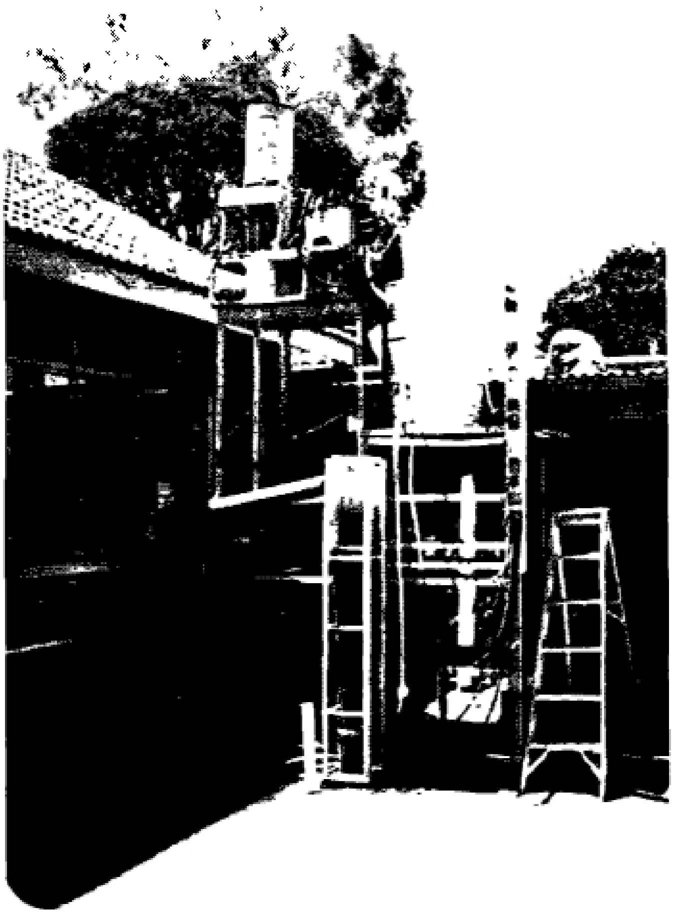
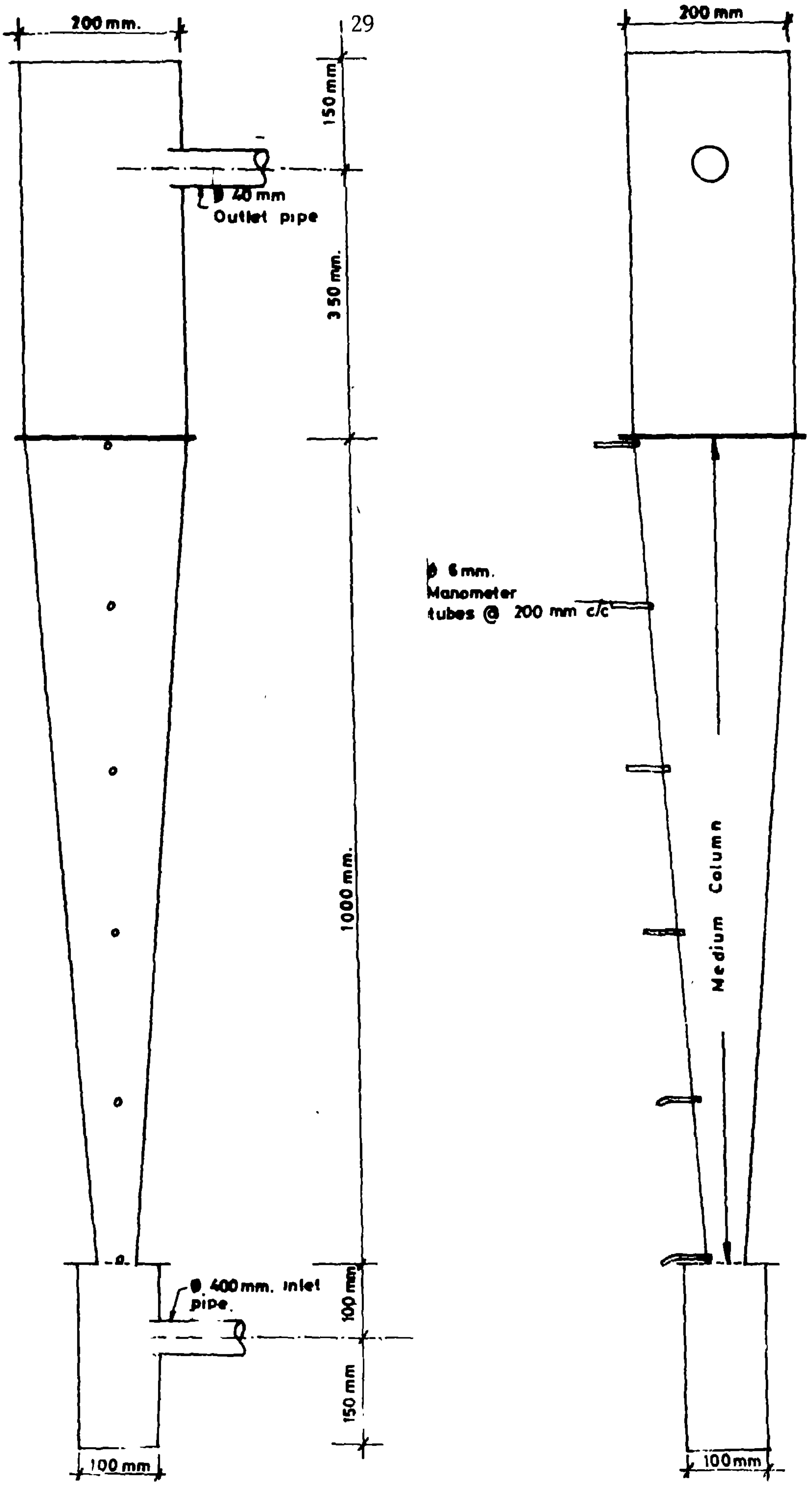


Figure 17. Tapering perspex UGBF in the experimental set up.

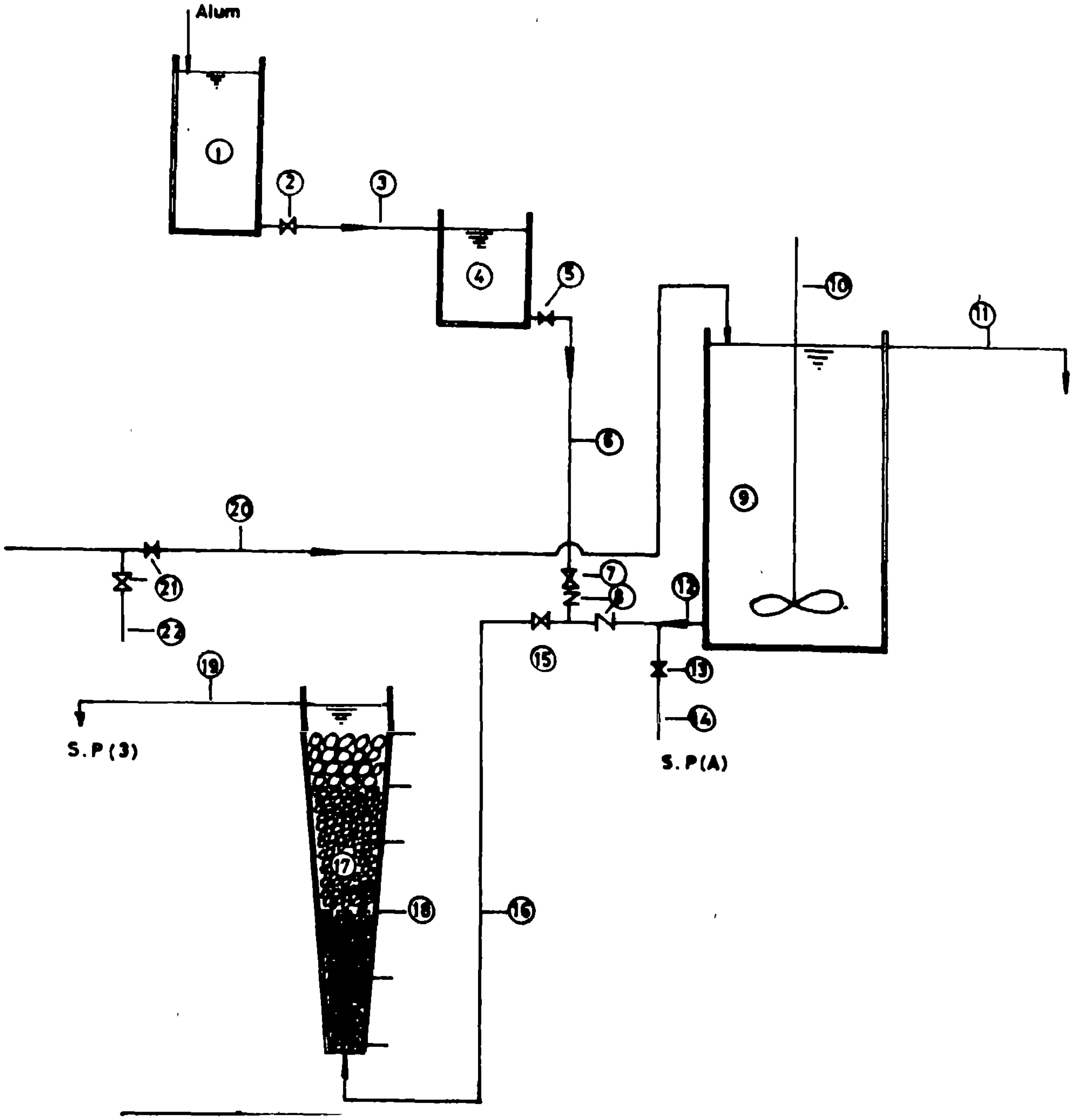
Figure 18. Close view of perspex UGBF showing the media.



SIDE VIEW
(Not to scale)

FRONT VIEW
(Not to scale)

Figure 19. Drawing of perspex UGBF.



Item No.	Description
1	25 l alum container
2	Valve
3	Rubber hose
4	Gravity doser
5	Valve
6	Hose pipe
7	Valve
8	Non-return valve
9	220 l drum
10	Stirrer
11	Overflow

Item No.	Description
12	Raw water outlet
13	Valve
14	Sampling point (SP) A
15	Valve
16	Raw water hose
17	UGBF unit
18	Piezometer connections
19	Overflow and SP B
20	Tap water inlet
21	Valve
22	Back wash connection

Figure 20. Schematic presentation of the experimental UGBF set up.

5.4 Methods

5.4.1 Physical properties of gravel media used

Some physical properties of the gravel media, e.g. size and porosity, are shown in table 2. These media were chosen because they are readily available in Kenya. Porosity was used as a parameter in the calculation of G and t values.

Table 2. Size and porosity of gravel media.

Size (mm)	Porosity (%)
1,5 - 3	37
3 - 6	42
6 - 13	43
13 - 25	44
25 - 39	50

5.4.2 Experimental set up

Figure 20 is a schematic presentation of the experimental set up. A detailed picture of a typical layout is illustrated in figure 15.

5.4.3 Raw water

Raw water was obtained by mixing a carefully prepared fine laterite soil with clean tap water in a 220 l drum. Initially 500 g of soil was put into the drum and 150 g added every 20 minutes and thoroughly mixed by a mechanical stirrer to maintain the desired turbidity range.

By taking samples from point 14 in figure 20 the raw water turbidity and its pH were monitored every 30 minutes. Raw water samples indicated an average pH of 7,8 requiring an alum dose of 72 mg/l for an optimum coagulation by the jar test apparatus.

5.4.4 Experimental procedure

The experimental procedure was conducted briefly as follows:

1) Turbidity was maintained within some range by addition of 150 g of soil after every 20 minutes into the 220 l drum and then stirring would follow by the help of a mechanical stirrer.

2) The alum dosage was maintained at the required level by the help of a gravity doser.

3) The flow into the raw water drum and that through the UGBF were maintained constant by the help of valves 15 and 21 in figure 15.

4) At the start and after every 30 minutes, the following data were got:
   - turbidity of raw water and amount of settleable solids,
   - head loss between the media layers,
   - flow through the UGBF,
   - one litre settling sample was put in an Imhoff cone.

5) The sample collected in 4) above, would be examined and the quality of flocs determined by the help of figure 13.

6) Samples were allowed to settle for 1½ hours and at intervals of 30 minutes the turbidity and amount of suspected solids were noted.

5.5 The UGBF runs

5.5.1 Galvanized iron tapering UGBF runs

Six runs were conducted on this UGBF unit, i.e. runs 1 - 6. A schedule for these six runs can be seen in table 3. Detailed data presentation can be seen in appendices III - VIII.

5.5.2 Galvanized iron cylindrical UGBF runs

For this unit, six runs were conducted. These are runs 7 - 12. The schedule of them can be seen in table 4. The data presentation can be seen in appendices IX - XIV.

Table 3. Schedule for runs 1 - 6.

Run		1	2	3	4	5	6
Flow (x 10^{-5} m^3/s)		10	10	10	5	5	5
Flow m/h		14,4 - 9,0	14,4 - 9,0	14,4 - 9,0	7,2 - 4,5	7,2 - 4,5	7,2 - 4,5
Alum dose (mg/1)		36	36	36	72	72	72
Range of turbidity (NTU)		131	140 - 150	161 - 368	254 - 435	280 - 448	210 - 400
Media size (mm)	200 mm Top	38 - 64	19 - 38	19 - 38	19 - 38	13 - 25	13 - 25
	200 mm	19 - 38	6 - 13	13 - 25	13 - 25	13 - 25	13 - 25
	200 mm	6 - 13	6 - 13	13 - 25	13 - 25	6 - 13	13 - 25
	200 mm	3 - 6	3 - 6	6 - 13	6 - 13	6 - 13	6 - 13
	200 mm Bottom	1,5 - 3	3 - 6	6 - 13	6 - 13	6 - 13	6 - 13

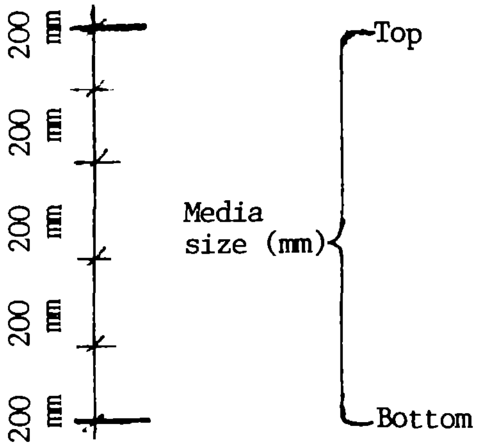
Table 4. Schedule for runs 7 - 12.

Run		7	8	9	10	11	12
Flow (x 10^{-5} m^3/s)		10	28	24	10	24	28
Flow m/h		11,5	32,1	27,5	11,5	27,5	32,1
Alum dose (mg/l)		36	13	15	36	15	13
Range of turbidity (NTU)		126 - 288	300 - 400	234 - 560	300 - 496	168 - 368	
200 mm	Top	3 - 6	3 - 6	3 - 6	3 - 6	13 - 25	13 - 25
200 mm		3 - 6	3 - 6	3 - 6	3 - 6	13 - 25	13 - 25
200 mm	Media size (mm)	3 - 6	3 - 6	1,5 - 3	1,5 - 3	6 - 13	6 - 13
200 mm		1,5 - 3	1,5 - 3	1,5 - 3	1,5 - 3	6 - 13	6 - 13
200 mm	Bottom	1,5 - 3	1,5 - 3	1,5 - 3	1,5 - 3	3 - 6	3 - 6

5.5.3 Tapering perspex UGBF runs

For this case only two runs were done, i.e. runs 13 and 14. The schedule for these runs can be seen in table 5. The data presentation can be seen in appendices IX and XIV.

Table 5. Schedule for runs 13 and 14.

Run	13	14
Flow (x 10^{-5} m^3/s)	10	10
Flow m/h	14,4 - 9,0	14,4 - 9,0
Alum dose (mg/l)	36	36
Range of turbidity (NTU)	400 - 600	384 - 600
 Top	6 - 13	6 - 13
	6 - 13	6 - 13
Media size (mm)	6 - 13	6 - 13
	6 - 13	6 - 13
Bottom	6 - 13	6 - 13

5.6 Presentation of results

5.6.1 GS tapering UGBF runs

The time for run 1 was only half an hour. The quick head loss development from 380 mm to 801 mm indicated that the media selected would not be suitable for flocculator media. The alum dosage was maintained at 36 mg/l.

The UGBF was able to reduce the influent turbidity of 140 NTU to 31 NTU after half an hour settlement of the sample. The Gt value increased from 7600 to 11260 during this run.

Run 2 lasted also half an hour. The head loss during the run rose from 302 mm to 342 mm. The alum dosage was maintained at 36 mg/l. The UGBF was able to reduce the turbidity from 150 NTU to 60 NTU after half an hour settlement. The floc quality according to floc comparator (see figure 13) was 4. The value of Gt varied from 7000 to 8000 during the run time.

Run 3 had coarser gravel media than runs 1 and 2 as shown in table 3. This run went on for two hours. During this time the head loss development was from 35 mm to 292 mm. The effluent turbidity variation with Gt and raw water turbidity is illustrated in figure 21. The Gt value developed from 4800 to 12500. Figure 21 reveals that effluent turbidity levels of less than 20 NTU were obtained when the Gt value was between 8500 and 12500. The corresponding head losses were 347 and 931 mm respectively. The floc quality according to floc comparator was 4.

For run 4, the type of gravel media used was similar to that of run 3. The flow through the flocculator was maintained at 5 x 10^{-5} m^3/s (7,2 to 4,5 m/h). The alum dosage was maintained at the level of 72 mg/l. The Gt value varied from 4600 to 12000. The head loss shot from 35 mm to a maximum value of 363 mm and then started to fall. The residual turbidity after treatment remained high as can be seen in figure 22. The duration of the run was four hours.

The flow for run 5 was 5 x 10^{-5} m^3/s (i.e. flows of 7,2 to 4,5 m/h) and the alum dosage was maintained at 72 mg/l. Run 5 had a duration of 4½ hours. The effluent turbidity remained very high as can be seen in figure 23. The Gt value at the start was around 4800 and developed to 11300. The head loss rose from 20 mm to 473 mm. The detailed data presentation can be seen in appendix VII. The floc quality varied between 4 and 5.

The media used for run 6 is shown in table 3. The flow maintained in the UGBF was 5 x 10^{-5} m^3/s (i.e. flow of 7,2 to 4,5 m/h). The alum dosage was maintained at the level of 72 mg/l. The effluent turbidity improved a lot after the Gt value exceeded 12100 as can be seen in figure 24. The head loss development over the duration of the run was from 79 mm to a maximum of 1002 mm and then dropped to 810 mm. This media did not prove very promising mainly because of the low time duration of the run.

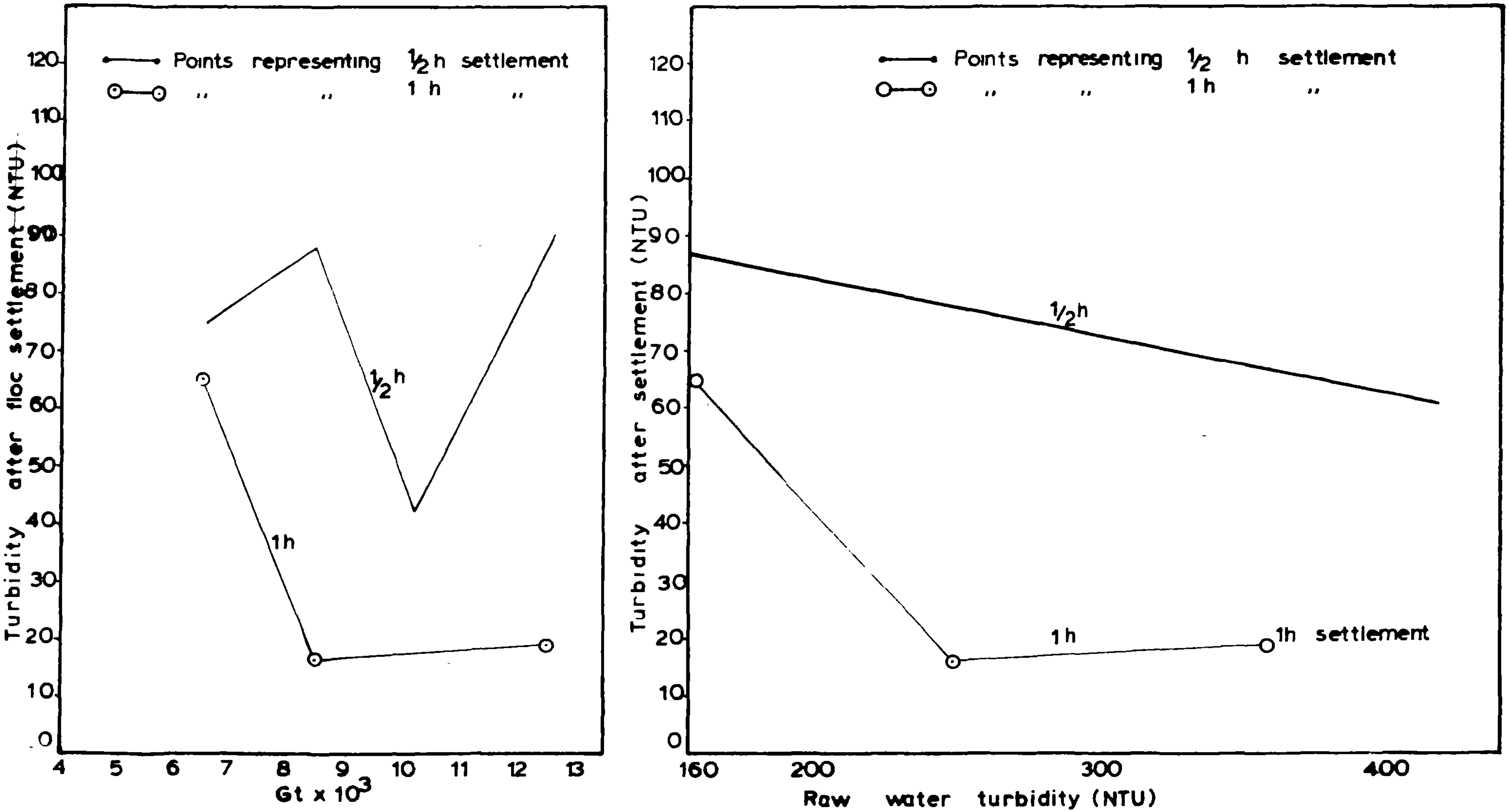


Figure 21. Effluent turbidity after settlement versus Gt and raw water turbidity (run 3).

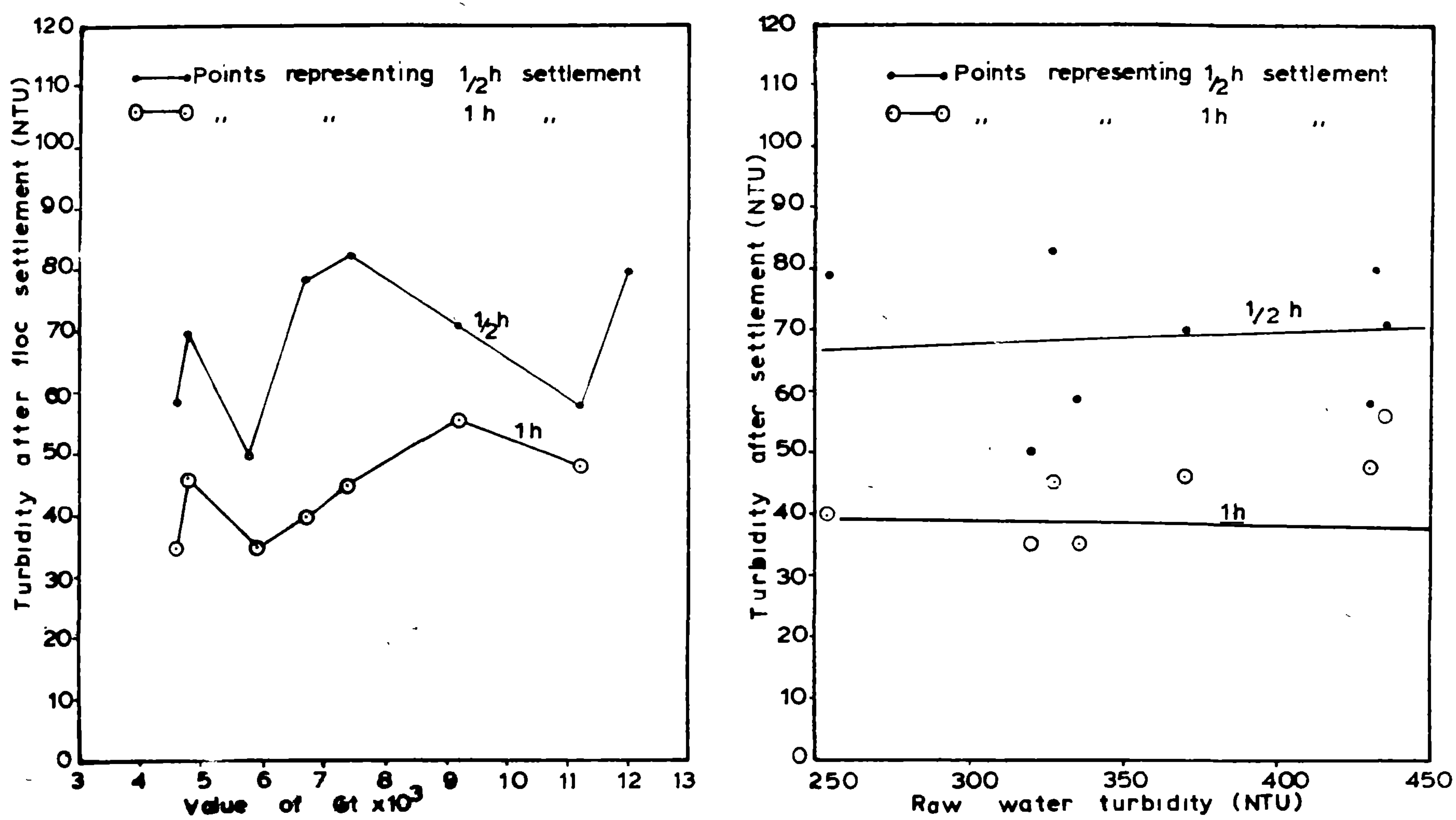


Figure 22. Effluent turbidity after settlement versus Gt and raw water turbidity (run 4).

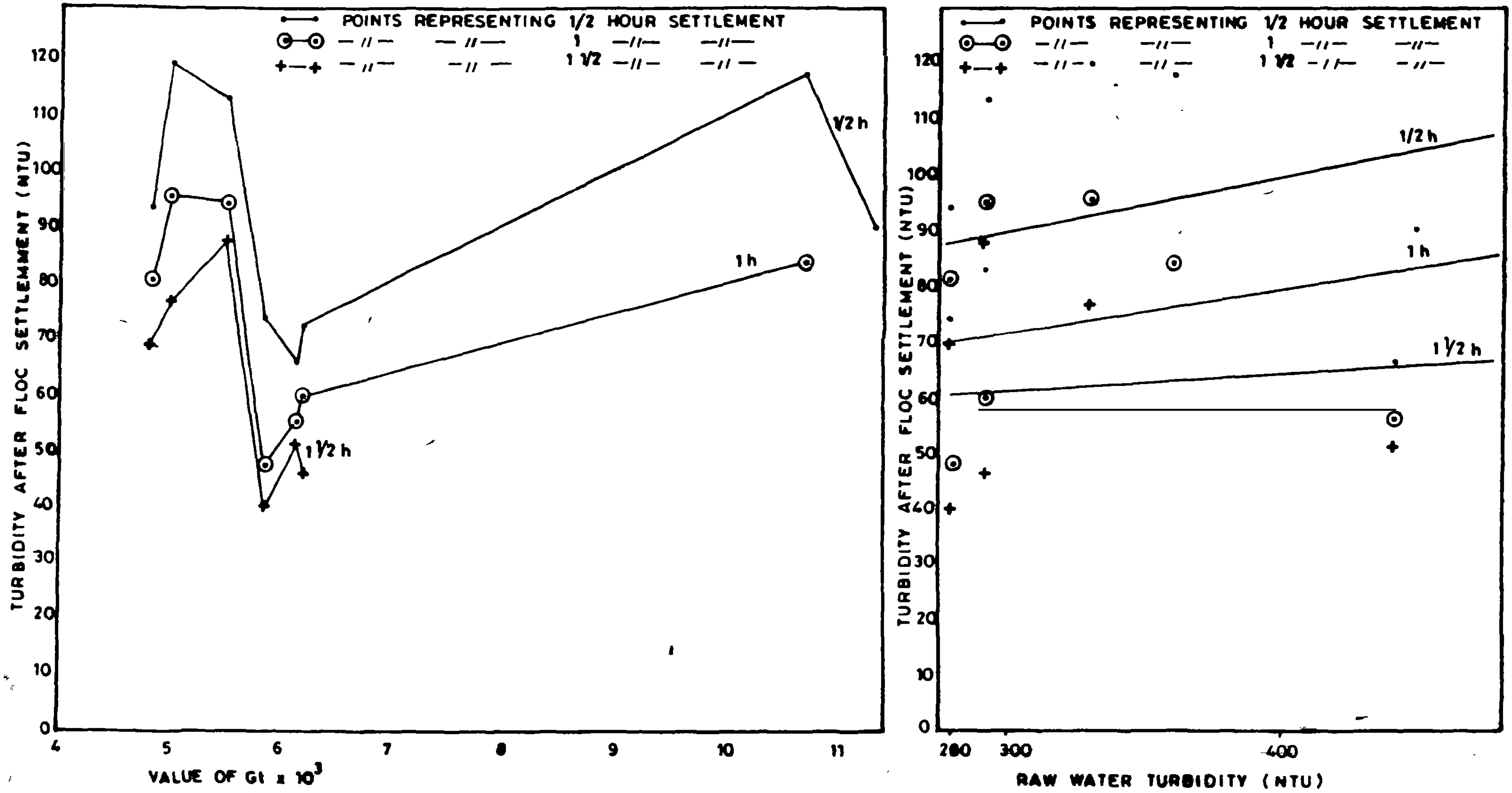


Figure 23. Effluent turbidity after settlement versus Gt and raw water turbidity (run 5).

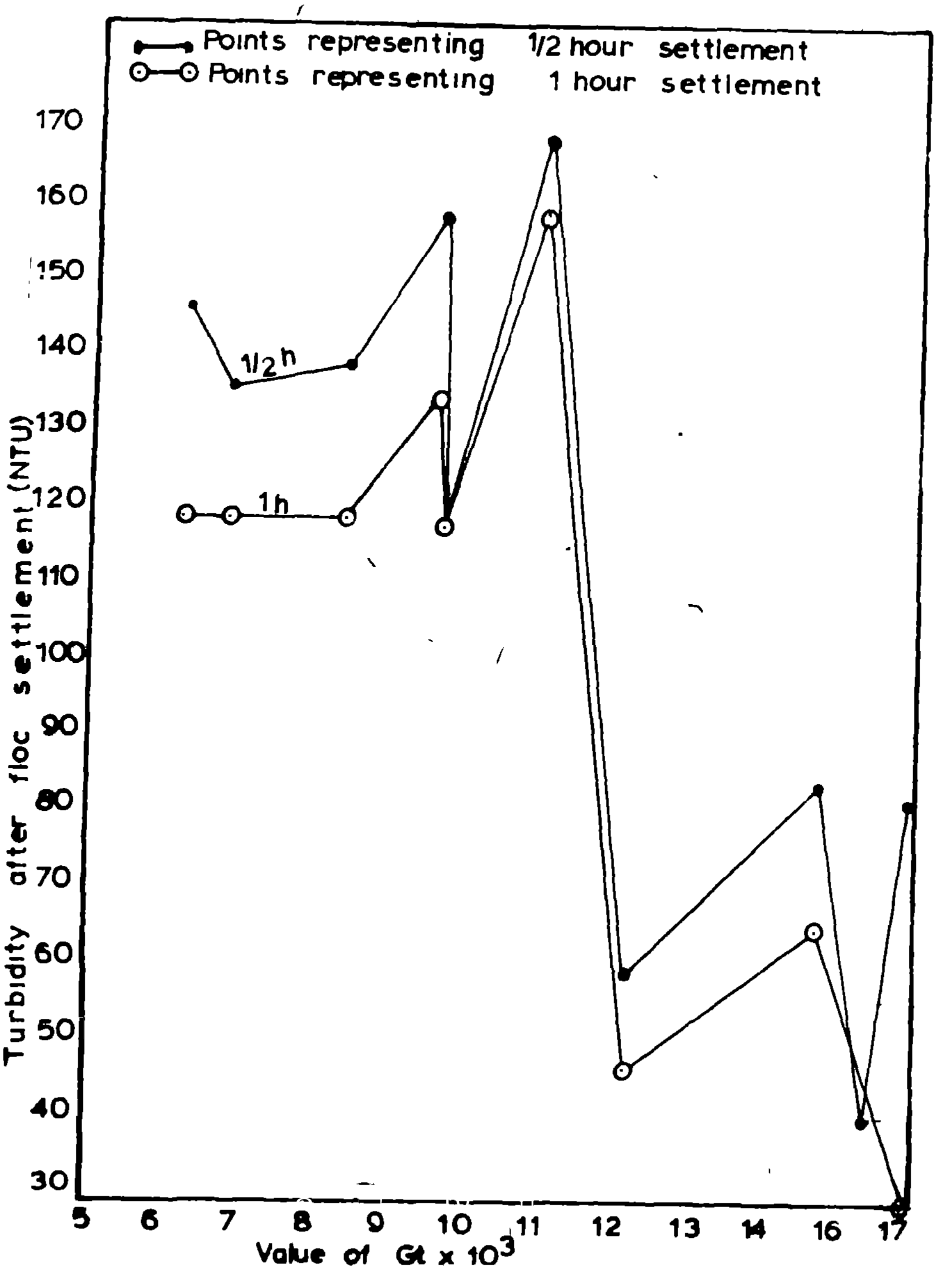


Figure 24. Effluent turbidity after settlement versus Gt (run 6).

5.6.2 Cylindrical GS UGBF

The number of runs conducted on this UGBF was runs 7 - 11. These series of runs results can be seen in appendices IX - XIII.

Run 7 had a run period of 8½ hours. The flow was maintained at 10 x 10^{-5} m^3/s (i.e. flow 11,5 m/h). The turbidity level varied from 126 NTU to 400 NTU. The Gt value varied from 8400 to 55000. The gravel media used can be seen in table 4.

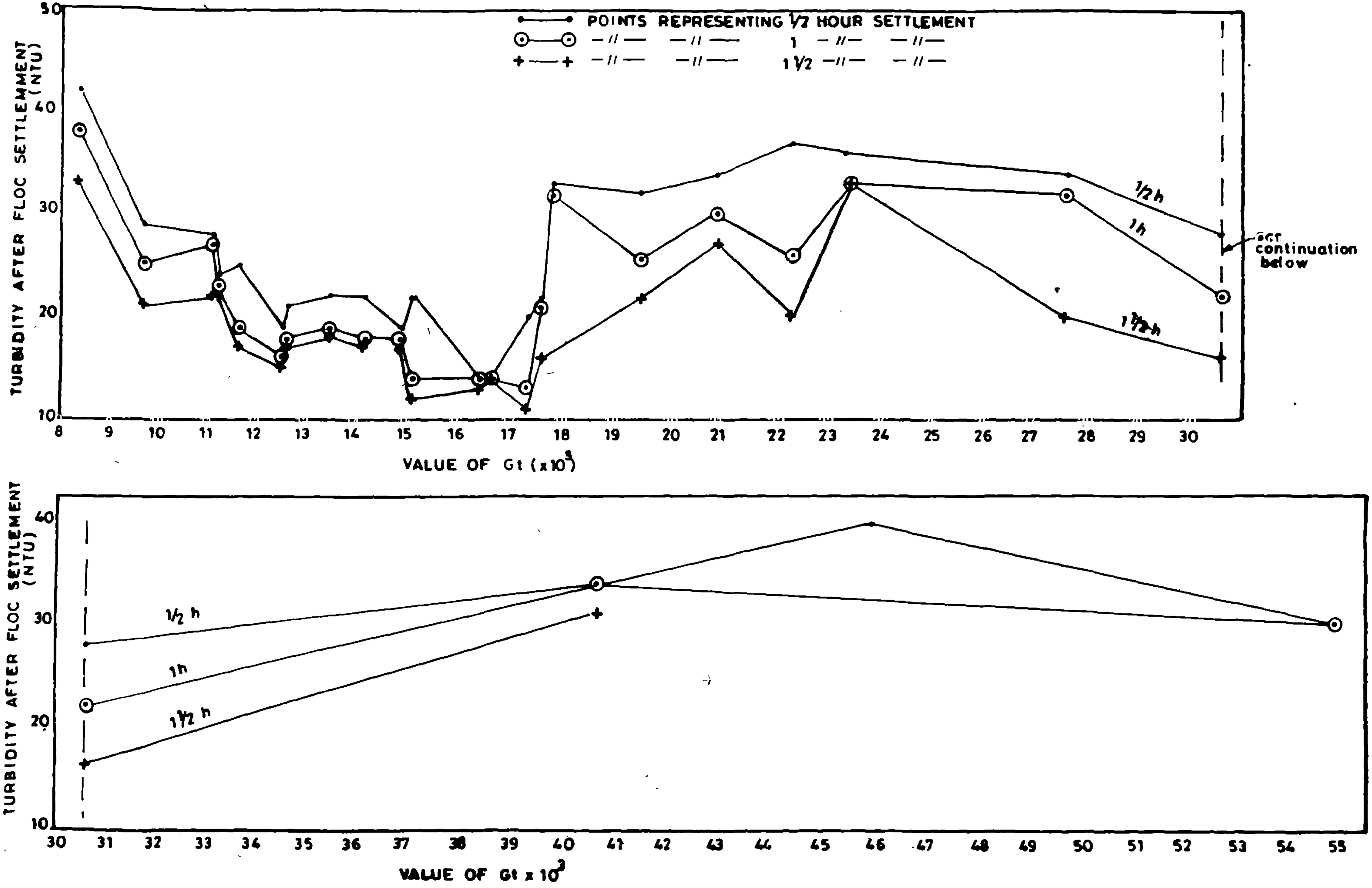


Figure 25. Effluent turbidity after settlement versus Gt (run 7).

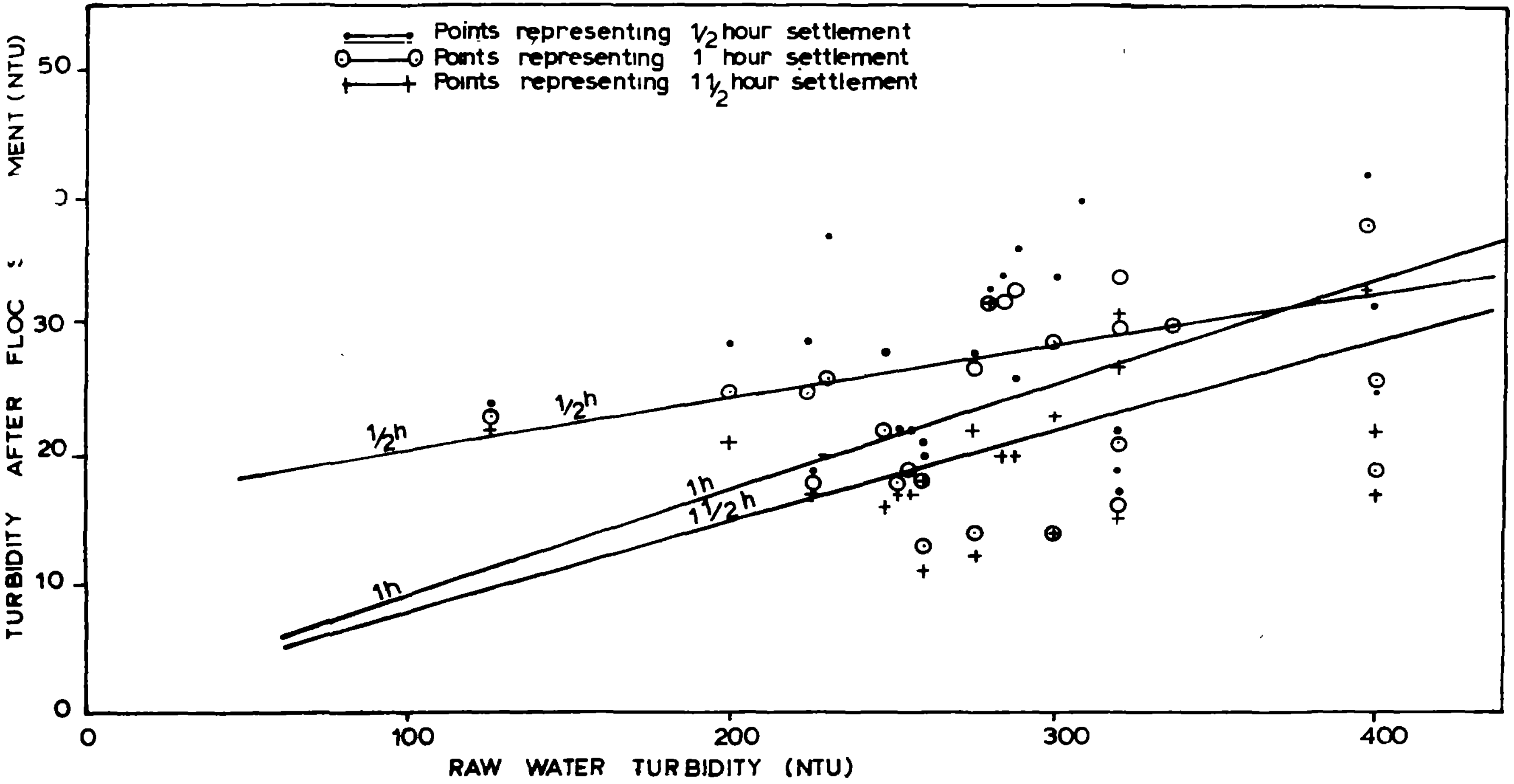


Figure 26. Effluent turbidity after settlement versus raw water turbidity (run 7).

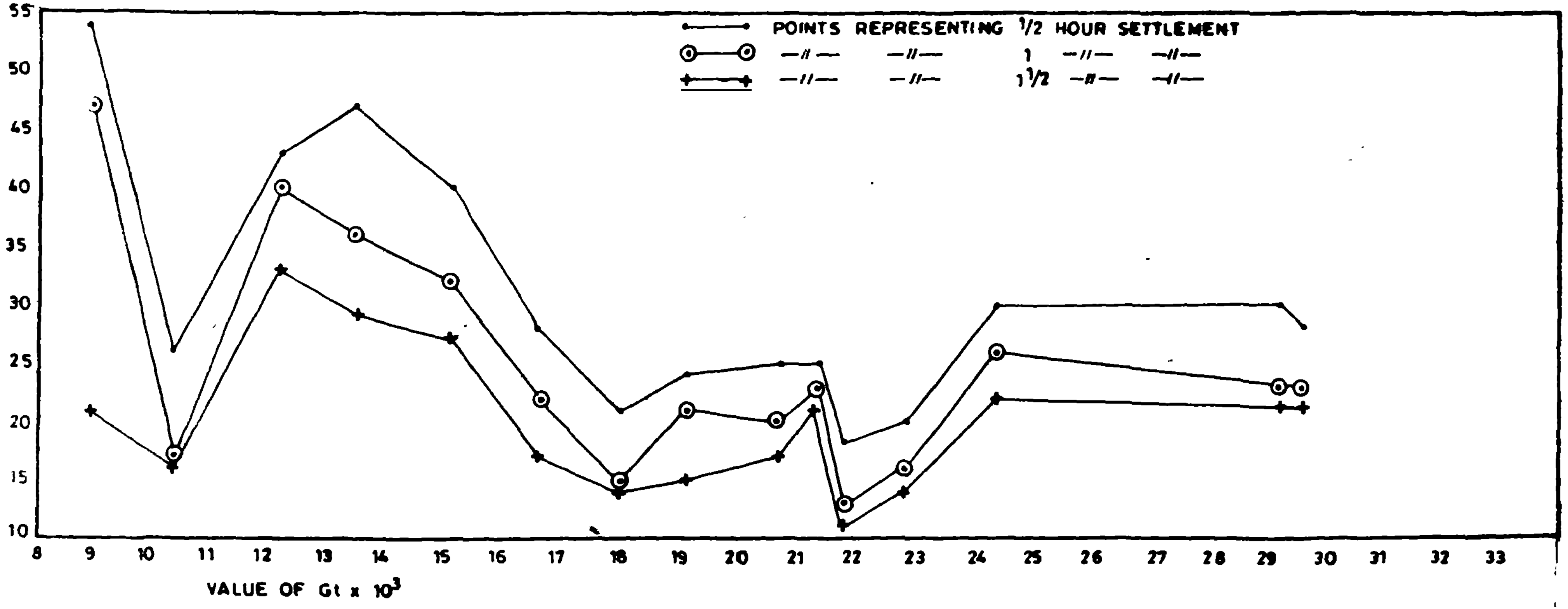


Figure 27. Effluent turbidity after settlement versus Gt (run 9).

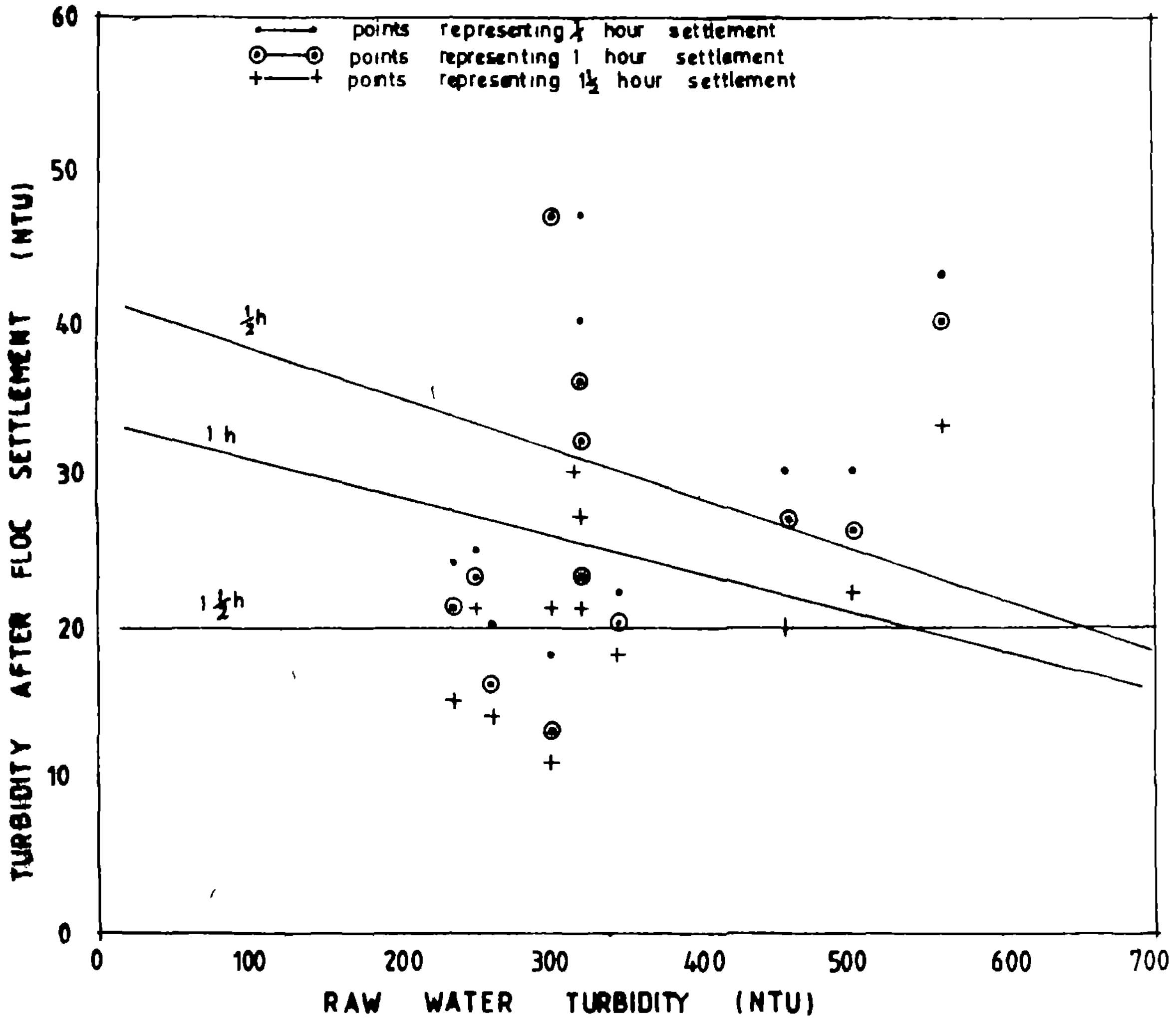
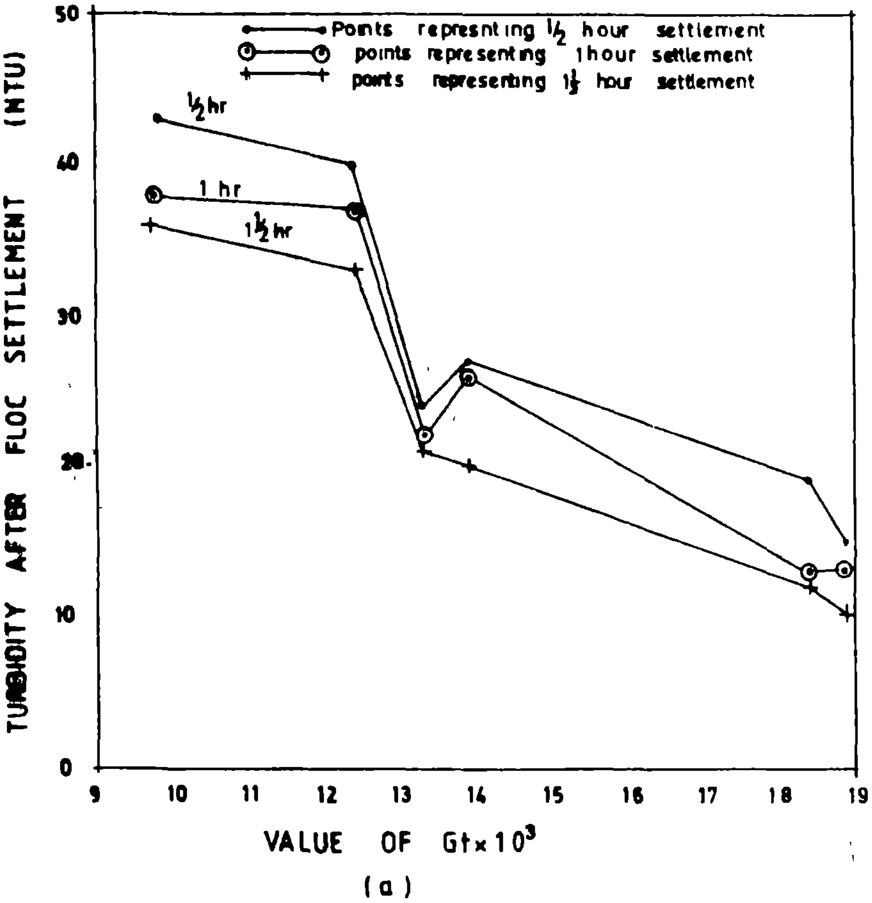


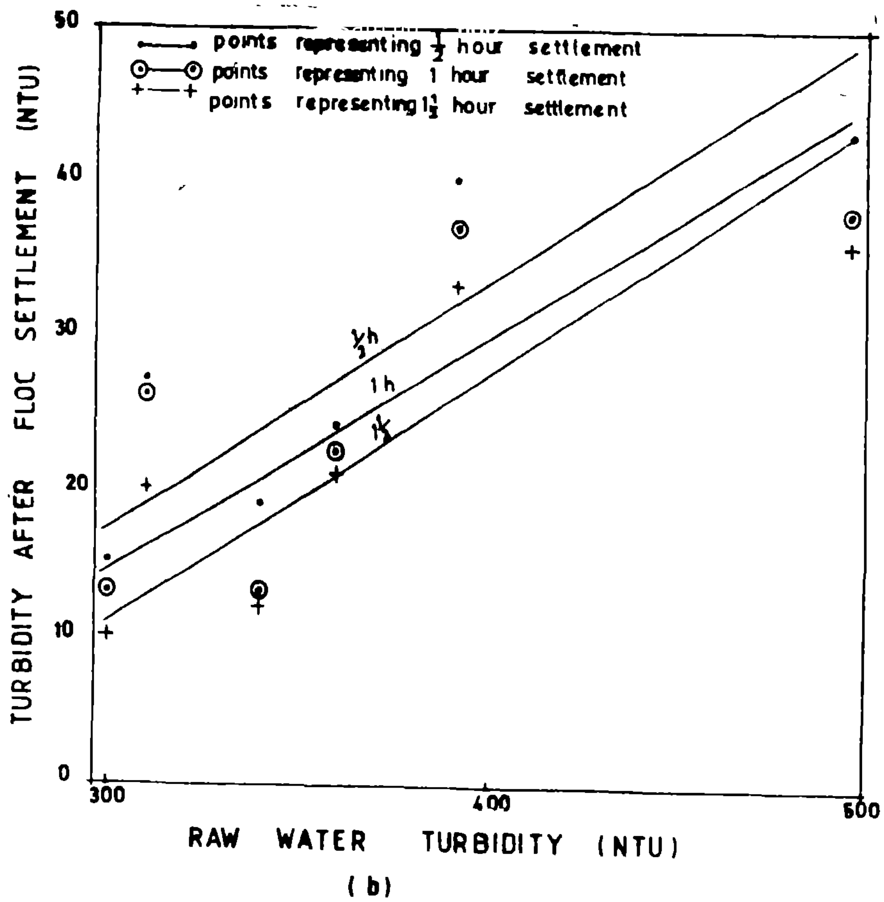
Figure 28. Effluent turbidity after settlement versus raw water turbidity (run 9).

The raw water turbidity in run 10 was maintained between 300 and 496 NTU. The effluent turbidity was generally below 43 NTU. The quality of the flocs after coagulation-flocculation was 5. The head loss development over the period of 3 hours was from 89 mm at the start to 386 mm.

The gravel media used for run 11 is shown in table 4. The raw water flow was 24 x 10^{-5} m^3/s (i.e. flow is 27,5 m/h). The raw water turbidity was maintained between 170 and 370 NTU. This data can be seen in figure 30. The alum dosage was maintained at 15 mg/l. The duration of the run was 5 hours. The effluent turbidity remained generally below 30 NTU. This value of Gt over this area was 6000 to 15800. The head loss within this range of Gt was 45 mm to 655 mm. Figure 30 has the necessary graphs of the performance for this run.



(a)



(b)

Figure 29. Effluent turbidity after settlement versus Gt and raw water turbidity (run 10).

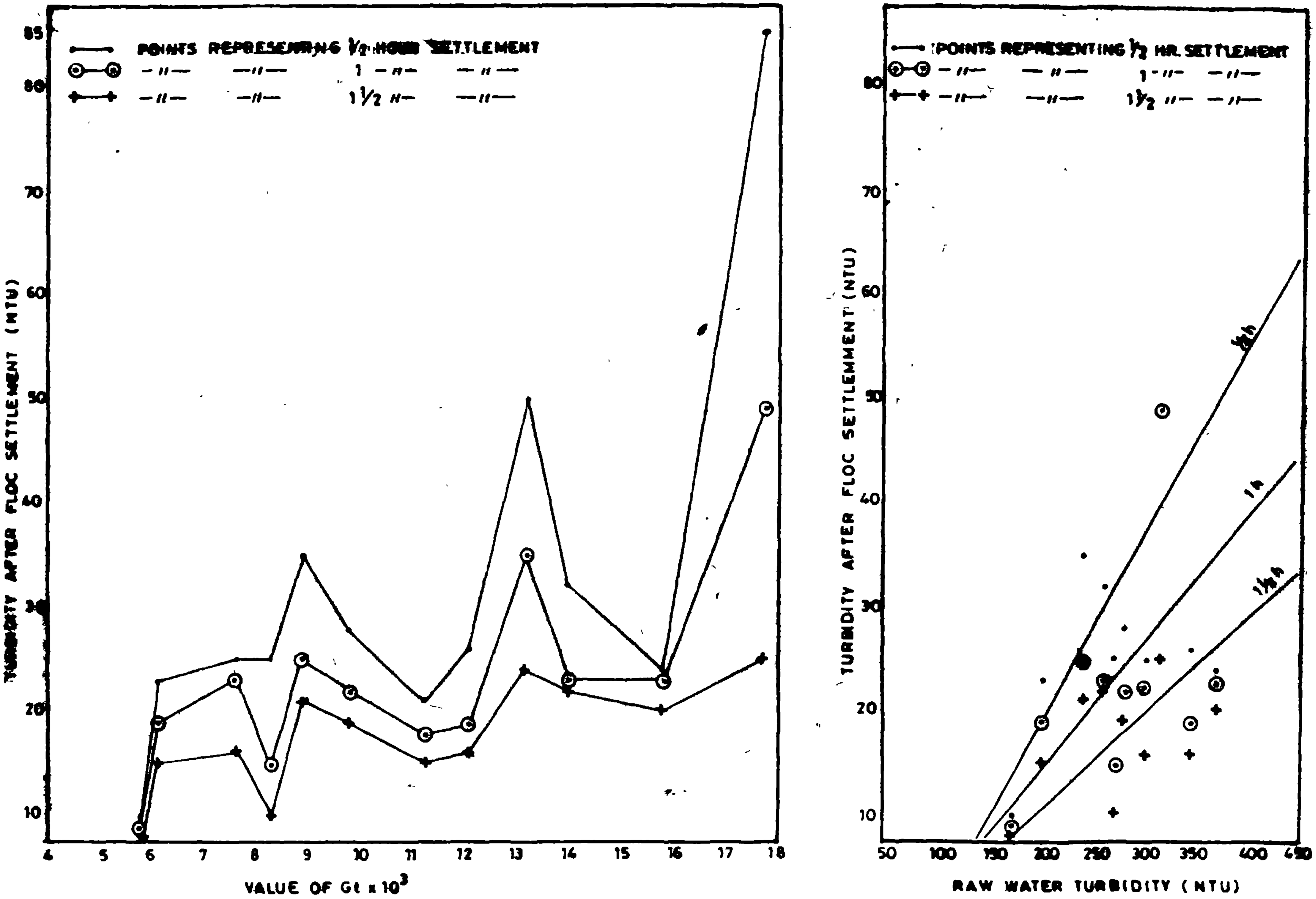


Figure 30. Effluent turbidity after settlement versus Gt and raw water turbidity (run 11).

The range of Gt that gave effluent turbidities less than 30 NTU varied from 8400 to 17500. The whole Gt range gave effluent turbidity of less than 40 NTU as can be seen in figures 26 and 27. The head loss development over the 8½ hour run was from 64 mm to 345 mm. The detailed data is represented in appendix IX. The flocs produced were of very high quality. Using the comparator (see figure 13) the flocs were rated as of the 5th grade. The levels of suspended solids (SS) can be seen in appendix IX.

After backwashing the media in run 7, run 8 commenced. The period of this run was 2½ hours. The detailed data record for run 8 can be seen in appendix X. The initial flow was 28 x 10^{-5} m³/s (i.e. flow 32,1 m/h). After the start of the experiment, the flow began to decrease with time. This run was considered a failure since without holding the flow and dosage constant, the data so obtained can be difficult to interpret properly. The dosage was held at 13 mg/1 during the experiment. For this run no graphical presentation is available.

The gravel media used for run 9 is shown in table 4. The length of the run was 7½ hours. The flow was maintained at 24 x 10^{-5} m³/s (i.e. flow is 27,5 m/h) and the alum dosage was 15 mg/1. For the Gt range of 9000 to 30000, the effluent had turbidity level of less than 40 NTU. The lowest values of effluent turbidity were recorded when the value of Gt was from 16600 to 29500. This information can be seen in figures 27 and 28. The turbidity within this range of Gt was below 25 NTU. The raw water turbidity varied from 235 to 560 NTU. From figure 28 it can be seen that raw water of high turbidity level resulted in a low effluent turbidity level. The head loss development was from 68 mm to 969 mm. The head loss range when the UGBF exhibited the best performance was 209 mm to 969 mm. These data can be seen in appendix XI. The floc quality was between 4 and 5 according to the floc comparator in figure 13.

The gravel media used for run 10 was the same as that for run 9. After backwashing the UGBF was subjected to the same flow as that of run 9. The run had a duration of 3 hours. The alum dosage was maintained at a level of 36 mg/l. From figure 29 it can be seen that the turbidity of effluent improved quite a lot. The substantial improvement in the turbidity occurred when the Gt value exceeded 12400. The corresponding range of head loss was 153 mm to 386 mm.

After bachwashing the UGBF after run 11, run 12 was started. The alum dosage was the same as for run 11. The flow was 28,2 x 10^{-5} m^3/s (i.e. flow 32,1 m/h). It proved difficult to hold this flow constant. The run was considered a failure.

5.6.3 Tapering perspex UGBF runs

Two runs were conducted on this unit. This unit was an improvement on the tapering GS UGBF. It had a small container for suspended solids. This unit had an improved performance.

Run 13 had media similar to the one shown in table 5. For this run a homogeneous gravel media was used. The flow was maintained at the level of 10 x 10^{-3} m^3/s (i.e. flow is 9,0 to 14,4 m/h). The alum dosage was 36 mg/l and the turbidity of raw water ranged from 400 to 600. The effluent turbidity after one hour settlement was generally below 50 NTU as can be seen in figure 31. The range of Gt over this period when the effluent turbidity remained below 50 NTU was from 3700 to 9300. The head loss development over this range was from 39 mm to 192 mm. The duration of the run was 6 hours. At the time of backwashing the UGBF, the flow was still at the original value level.

The performance of this UGBF after backwashing was studied in run 14. The flow and dosage were maintained at the same values as those of run 13. The turbidity range in the raw water was between 381 and 600 NTU. The turbidity level remained generally below 60 NTU. This information can be seen in figure 32. The duration of the run was 5½ hours. The UGBF showed a gradual increase in head loss. At the start, the head loss was 24 mm. The head loss at the time of stopping the run was 142 mm.

5.7 Evaluation of the results

The criteria to be used for evaluation of the performance of the UGBF will be:

a) flow,

b) alum dosage,

c) duration of the run in hours,

d) effluent turbidity after 1 hour settlement,

e) head loss development,

f) floc quality and settlement properties.

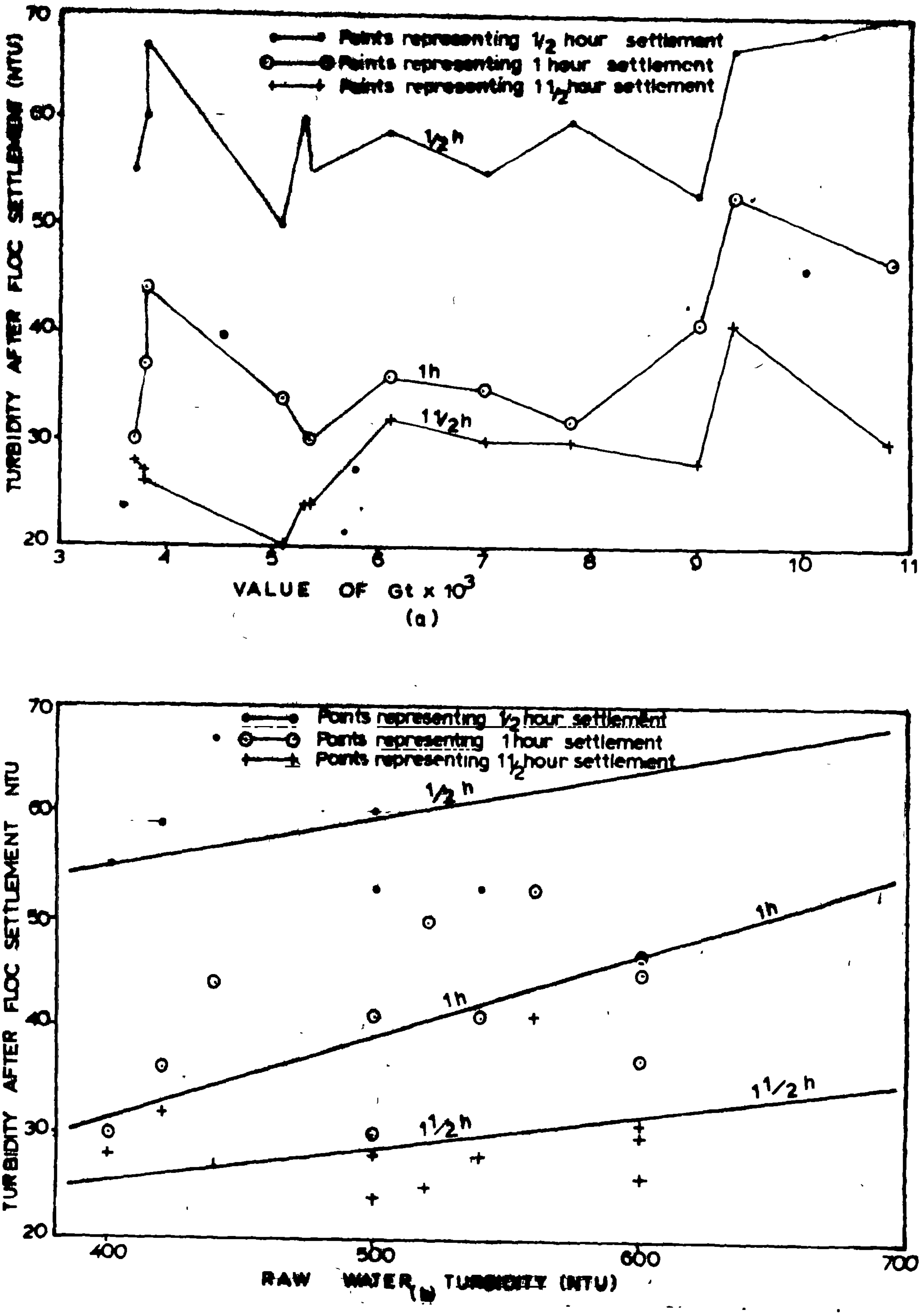


Figure 31. Effluent turbidity after settlement versus Gt and raw water turbidity (run 13).

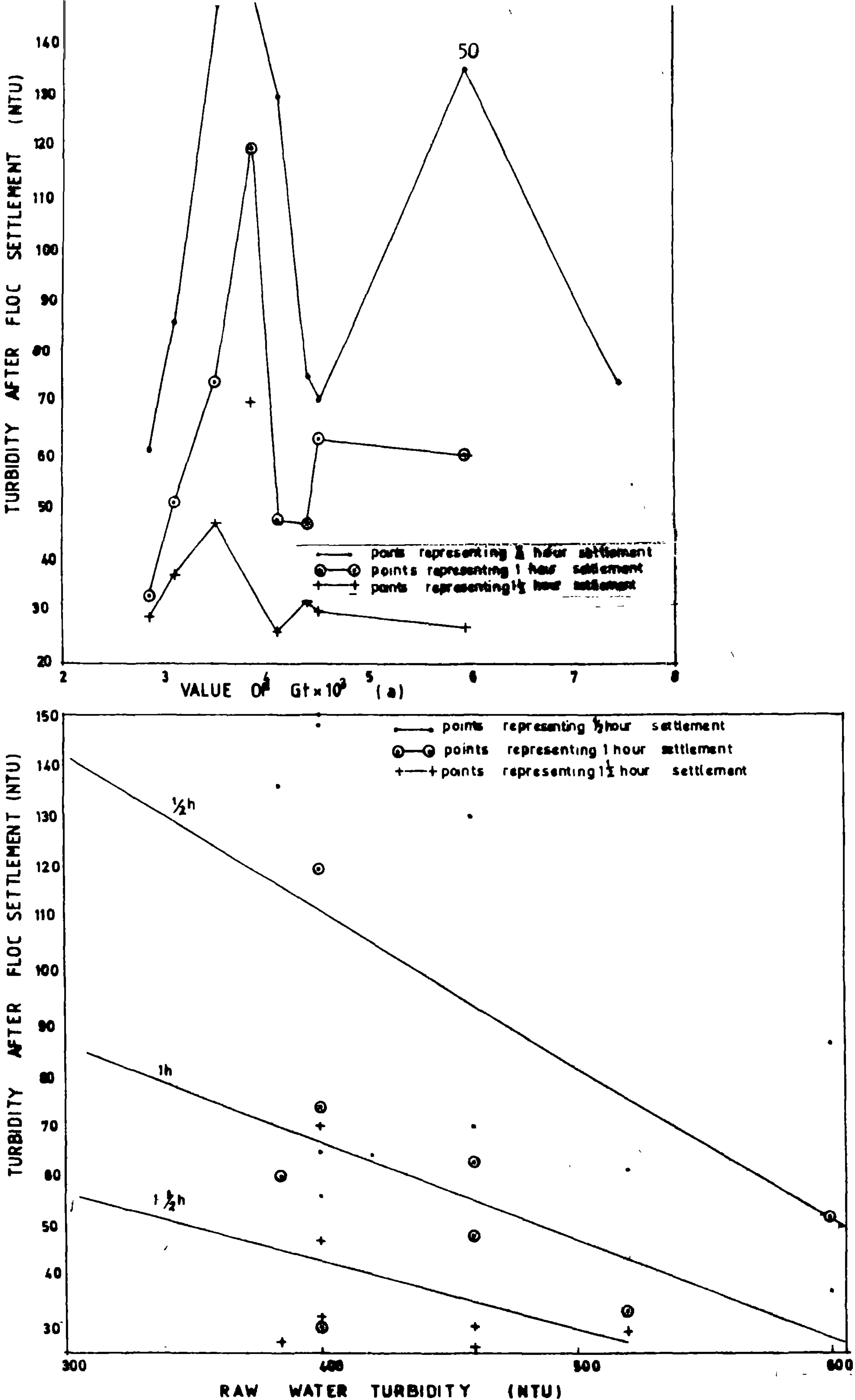


Figure 32. Effluent turbidity after settlement versus Gt and raw water turbidity (run 14).

In the case of tapering galvanized iron UGBF the run with the best performance was run 4. It had a flow of 5 x 10^{-5} m^3/s (i.e. flow 7,2 to 4,5 m/h) and alum dosage of 72 mg/l. The duration of the run was 4 hours. The effluent turbidity after one hour settlement remained generally below 50 NTU. The head loss development over the 4 hours was below 400 mm. The floc quality generally remained between grades 4 and 5.

For the case of cylindrical galvanized UGBF the run which had the best performance was run 7. The flow was 10 x 10^{-5} m^3/s (11,5 m/h). The alum dosage was 36 mg/l. The effluent turbidity after one hour settlement was generally below 35 NTU. The head loss development over the duration of the run was from 35 mm to 969 mm. The floc quality remained between grade 4 to 5. The amount of floc after one hour settlement was 4,5 to 0,6 ml/l.

For the case of improved tapering UGBF made out of perspex, run 13 had the best performance. The flow was 10 x 10^{-5} m^3/s (14,4 to 9,0 m/h). The alum dosage was 36 mg/l. The run was conducted for 6 hours. The effluent turbidity after one hour settlement was below 50 NTU. The head loss development was from 39 mm to 192 mm. The floc quality was between grades 4 and 5. The floc settlement quality as measured by Imhoff cone after one hour settlement remained between 0,7 to 8,0 ml/l.

6 DISCUSSION

UGBF runs were of a short duration. The run that gave the longest duration was run 7 which lasted 8½ hours. The effluent turbidity was generally below 35 NTU. The clogging of the media showed itself by a sudden head loss development between the first and the second piezometric tubes. This phenomenon indicated clogging of the first layer of the media. The methodology of tapping raw water and passing it through the UGBF showed that a lot of suspended solids (SS) finally managed to enter the bed. The SS then lodged themselves in the first layers of the media causing a sudden head loss development.

In normal cases when water is tapped from a river, an intake well, an intake weir or a dam, most of SS will have settled already. If such raw water is treated, the UGBF would have very long runs.

To avoid such a sudden head loss development which then results in clogging of the media, coarse media could be used like that which was used for run 13. This would then mean that the SS would find it difficult to lodge themselves between the media grains. The only problem with this arrangement was that the effluent turbidity was not as good as that obtained when graded media was used.

7 CONCLUSIONS AND RECOMMENDATIONS

a) For tapering UGBF the gravel media grading from fine to coarse in the direction of flow gave a very short run. The absence of settleable solids chamber in the galvanized iron unit aggravated the performance.

b) Inclusion of settleable solids chamber for the case of tapering perspex unit improved the duration of the run when the media was graded from fine to coarse in the direction of the flow.

c) The use of homogeneous gravel of size 6 to 13 mm in tapering perspex UGBF gave good results as far as the effluent quality and run duration were concerned.

d) For cylindrical galvanized iron UGBF containing gravel of size 1,5 to 3 mm and 3 to 6 mm graded from fine to coarse in the direction of flow gave good results. A long run duration and good effluent quality were obtained.

e) To get a reasonable run duration in a UGBF it is necessary that a settleable solids chamber should be included at the influent part of the UGBF.

f) In general, the best performance for tapering units was obtained when the Gt value was between 4600 and 12000 while treating a flow of 5 x 10^{-5} m^3/s (7,2 to 4,5 m/h). The corresponding head loss was below 500 mm. After the head loss of such magnitude is reached, then the UGBF should be backwashed. However a better judgement as to when backwashing is required should be made depending on the effluent quality.

g) For cylindrical galvanized iron UGBF the best performance was obtained when the graded gravel media was of size 1,5 to 3 mm and 3 to 6 mm and thicknesses were 400 mm and 600 mm respectively placed with fine to coarse media in the direction of flow. The flow was 10 x 10^{-5} m^3/s (11,5 m/h). The head loss value of less than approximately 400 mm gave the best effluent. The Gt value ranged from about 8000 to 54500. The dose was 36 mg/l.

h) The UGBF are cheap structures to construct and operate compared to the normal coagulation-flocculation units. The present worth analysis shown in appendix XVI proves this. Their use should be encouraged especially for small water supply schemes.

i) The apparent short duration runs could suit small water supply schemes which operate for a period of 8 to 10 hours. In field situations where the level of suspended solids in the raw water is low, the UGBF should operate for longer runs.

j) From visual observation of the performance of the tapering perspex UGBF it was clearly visable how the flocs formed as they moved upwards in the bed. The heaviest flocs tried to settle back from the upper half of the bed. The upward flow opposed this settlement. These settling particles came into contact with finer particles and ended becoming bigger flocs.

k) From the study done, it can be concluded that UGBF of a uniform cross section performs better than tapering UGBF. The performance is in relationship to the duration of the run, amount of floc and effluent turbidity.

l) For further research in the UGBF, it is recommended that a full scale plant would be constructed and its performance monitored.

m) Formation of flocs as they move up the UGBF should be studied.

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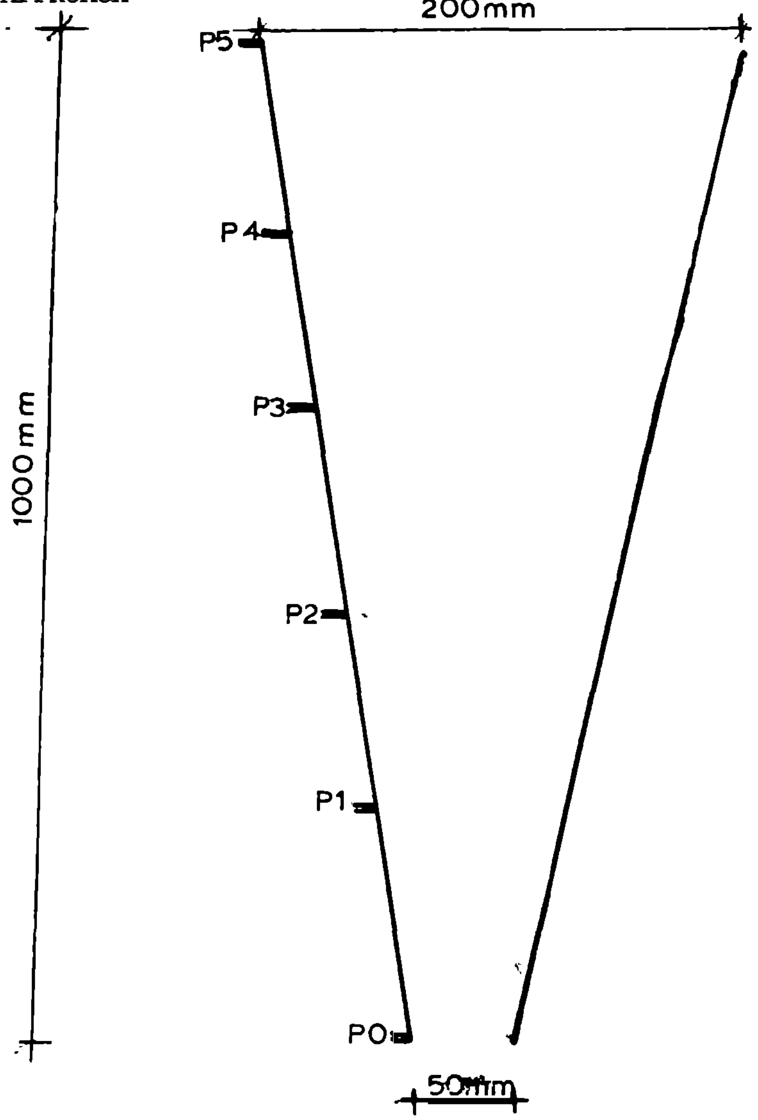
APPENDICES

APPENDIX I	Calculation of G, t and Gt for tapering UGBF - theoretical approach
APPENDIX II	Calculation of G, t and Gt for tapering UGBF - practical approach
APPENDIX III	Results of run 1 - tapering GS unit
APPENDIX IV	Results of run 2 - tapering GS unit
APPENDIX V	Results of run 3 - tapering GS unit
APPENDIX VI	Results of run 4 - tapering GS unit
APPENDIX VII	Results of run 5 - tapering GS unit
APPENDIX VIII	Results of run 6 - cylindrical GS unit
APPENDIX IX	Results of run 7 - cylindrical GS unit
APPENDIX X	Results of run 8 - cylindrical GS unit
APPENDIX XI	Results of run 9 - cylindrical GS unit
APPENDIX XII	Results of run 10 - cylindrical GS unit
APPENDIX XIII	Results of run 11 - cylindrical GS unit *
APPENDIX XIV	Results of run 13 - tapering perspex unit
APPENDIX XV	Results of run 14 - tapering perspex unit
APPENDIX XVI	Worth analysis

* Run 12 is failed so there is no appendix for it.

CALCULATION OF VALUES G, t AND Gt FOR TAPERING UGBF - THEORETICAL APPROACH



Volume of flocculator = ½ (0,0025 + 0,0400) x 1,000

= 0,0213 m^3

Volume available for flocculation

= media porosity x 0,0213

= 0,4 x 0,0213

= 0,0085 m^3

Discharge is 15/86400 m^3/s

Nominal flocculation time

$$= \frac{0,0085}{15/86400} = \underline{\underline{49 \text{ seconds}}}$$

Section $P_0 - P_1$ (see formulae 4 and 5)

Average velocity $= \frac{15/86400}{\text{av. x-area}} = \frac{15/86400}{0,0045} = 0,0386$ m/s

R_n $= \frac{dvP}{} = \frac{0,0075 \times 0,0386 \times 997,8}{0,96 \times 10^{-3}}$

$= 300,9$

Frictional factor f $= 150 \frac{(1 - \alpha)}{R_n} + 1,75$

$= 150 \frac{(1 - 0,4)}{300,9} + 1,75$

$= 2,05$

Head loss h $= \frac{f}{\theta} \frac{1 - \alpha}{\underline{\alpha^3}} \times \frac{L}{d} \times \frac{V2}{g} = 2,05 \frac{1 - 0,4}{\cancel{0,4^3}} \times \frac{0,2}{0,0075} \times \frac{0,0386^2}{9,81}$

$= 0,0973$ m

Volume available for flocculation

$= V = 0,4 V$

G $= \frac{h\rho gQ}{V} = \frac{0,0973 \times 997,8 \times 9,81 \times 15/86400}{\underline{0,96 \times 10^{-3} \times 0,4 \times 0,0045 \times 0,2}}$

$= 691,5$

t $= \frac{\cancel{V}}{15/86400} = \frac{\cancel{0,4 \times 0,0045 \times 0,2}}{15/86400}$ (s)

$= 2,07$ (s)

Gt $= 691,5 \times 2,07$

$= 1431,4$

Section $P_1 - P_2$

v $= 0,0187$ m/s

R_n $= 145,8$

f $= 2,37$

h $= 0,0263$ m

G $= 249,7\ s^{-1}$

t $= 4,29$ s

Gt $= 1071,2$

Section $P_2 - P_3$

v = 0,0109 m/s
R_n = 85,0
f = 2,81
h = 0,0106 m
G = 121,5 s^{-1}
t = 7,32 s
Gt = 889,4

Section $P_3 - P_4$

v = 0,0071 m/s
R_n = 110,7
f = 2,56
h = 0,0021 m
G = 43,8 s^{-1}
t = 11,2 s
Gt = 490,6

Section $P_4 - P_5$

v = 0,0050 m/s
R_n = 78
f = 2,9
h = 0,0012 m
G = 27,7 s^{-1}
t = 15,9 s
Gt = 440,4

CALCULATION OF VALUES G, t AND Gt FOR TAPERING UGBF - PRACTICAL APPROACH

(see figure 16 and appendix 1)

Section $P_0 - P_1$ at time interval 0 h

$$\text{Average velocity} = \frac{0{,}1 \times 10^{-3}}{0{,}0045} = 0{,}0222 \text{ m/s}$$

$$t = \frac{0{,}0045 \times 0{,}2 \times 0{,}37}{0{,}1 \times 10^{-3}} = 3{,}3 \text{ s}$$

$$R_n = \frac{0{,}000225 \times 0{,}0222 \times 997{,}8}{0{,}96 \times 10^{-3}} = 51{,}9$$

$$G = \frac{0{,}304 \times 997{,}8 \times 9{,}81 \times 0{,}1 \times 10^{-3}}{0{,}96 \times 10^{-3} \times 0{,}37 \times 0{,}0045 \times 0{,}2} = 965{,}0 \text{ s}^{-1}$$

Gt = 3184,6

Section $P_1 - P_2$

v = 0,0108 m/s

t = 7,8 s

R_n = 50,5

G = 296,9 s^{-1}

Gt = 2316,1

Section $P_2 - P_3$

v = 0,0063 m/s

t = 13,7 s

R_n = 67,1

G = 71,9 s^{-1}

Gt = 985,1

Section $P_3 - P_4$

v = 0,0041 m/s

t = 18,0 s

R_n = 121,5

G = 20,4 s^{-1}

Gt = 367,2

Section P_4 - P_5

v = 0,0029 m/s
t = 16,3 s
R_n = 153,7
G = 16,3 s^{-1}
Gt = 620,2

Section P_0 - P_1 at time interval ½ h

v = 0,0127 m/s
t = 5,8 s
R_n = 29,7
G = 1154,3 s^{-1}
Gt = 6694,9

Section P_1 - P_2

v = 0,0061 m/s
t = 13,7 s
R_n = 28,5
G = 157,4 s^{-1}
Gt = 2156,2

Section P_2 - P_3

v = 0,0036 m/s
t = 24,0 s
R_n = 35,5
G = 35,5 s^{-1}
Gt = 852,5

Section P_3 - P_4

v = 0,0023 m/s
t = 47,7 s
R_n = 68,1
G = 15,4 s^{-1}
Gt = 734,4

Section P_4 - P_5

v = 0,0017 m/s
t = 66,6 s
R_n = 90,1
G = 12,3 s^{-1}
Gt = 820,8

APPENDIX III

RESULTS OF RUN 1 - TAPERING GS UNIT

ead oint	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
) - P_1	304			965,0	3,3	3184,6	140	½ h = 31*			
								1 h = **			
								1½ h = ***			
1 - P_2	67	0	0,100	296,9	7,8	2316,1					
2 - P_3	7			71,9	13,7	985,1					
3 - P_4	1			20,4	24,3	495,8					
- P_5	1			16,3	38,0	620,2					
	380					7601,8					
) - P_1	763			1154,3	5,8	6694,9		½ h = 31		5	
								1 h =			
								1½ h =			
- P_2	33	½	0,057	157,4	13,7	2156,2					
2 - P_3	3			35,5	24,0	852,5					
3 - P_4	1			15,4	47,7	734,4					
- P_5	1			12,3	66,6	820,8					
	801					11258,8					

Value of turbidity after ½ hour settlement
" " " " 1 " "
* " " " " 1½ " "

Points P_0 to P_5 are piezometric points

SS is settleable solids

APPENDIX IV

RESULTS OF RUN 2 - TAPERING GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
P_0 - P_1	265			849,0	3,8	3226,1	140				
P_1 - P_2	20	0	0,100	162,3	7,8	1265,8					
P_2 - P_3	15			105,2	13,7	1441,5					
P_3 - P_4	1			22,0	20,9	459,5					
P_4 - P_5	1			17,1	35,0	598,1					
	302					6991,0					
	398			1040,5	3,8	3953,8	150	½ h = 60 1 h = 1½ h =			
	23	½	0,100	174,0	7,8	1356,8					
	19			120,9	13,7	1653,3					
	1			22,0	20,9	459,5					
	1			17,1	35,0	598,1					
	342					8021,5					

APPENDIX V

RESULTS OF RUN 3 - TAPERING GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	55			378,9	3,9	1477,8	161				
$P_1 - P_2$	15	0	0,1000	137,7	8,0	1101,6					
$P_2 - P_3$	3			47,0	14,0	658,6					
$P_3 - P_4$	1			22,0	21,4	470,8					
$P_4 - P_5$	1			17,1	34,5	590,0					
	75					4298,8					
$P_0 - P_1$	140			525,3	5,1	2679,1	161	½ h = 75 1 h = 65			
$P_1 - P_2$	28	½	0,0755	163,4	10,6	1732,0					
$P_2 - P_3$	4			47,2	18,5	873,2					
$P_3 - P_4$	1			19,1	28,3	540,5					
$P_4 - P_5$	1			14,9	45,7	679,2					
	174					6504,0					

RESULTS OF RUN 3 Cont'd

Head Point	loss (mm)	Time (h)	Flow ($\times 10^{-3}$ m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	305			807,6	5,1	4115,7	250	½ h = 88			
								1 h = 16			
								1½ h =			
$P_1 - P_2$	32	1	0,0755	182,0	10,6	1929,2					
$P_2 - P_3$	8			66,8	18,5	1236,1					
$P_3 - P_4$	1			19,1	28,3	540,6					
$P_4 - P_5$	1			14,9	45,7	679,2					
	347					8500,8					
$P_0 - P_1$	502			702,8	10,3	7239,0		½ h = 90			
								1 h = 19			
							360	1½ h =			
$P_1 - P_2$	22	1½	0,0377	106,6	21,2	2260,0					
$P_2 - P_3$	5			37,3	37,1	1383,8					
$P_3 - P_4$	1			14,1	56,7	797,3					
$P_4 - P_5$	1			10,5	91,5	960,9					
	531					12641,0					

RESULTS OF RUN 3 Cont'd

ad int	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	 Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
- P_1	222			380,6	15,5	5899,9	368	½ h = 42 1 h = 1½ h =			
- P_2	6	2	0,0250	32,0	43,5	1392,0					
- P_3	1			13,6	56,0	761,6					
- P_4	1			10,0	85,5	855,0					
- P_5	1			9,2	137,2	1262,2					
	231					10170,7					

APPENDIX VI

RESULTS OF RUN 4 (Same media as in run 3) - TAPERING GS UNIT

Point	Head loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	4			72,3	7,7	556,7					
$P_1 - P_2$	2			35,5	16,0	568,0					
$P_2 - P_3$	2	0	0,0500	27,2	28,0	760,7	330	½ h =			
$P_3 - P_4$	1			15,6	42,8	667,7		1 h =			
$P_4 - P_5$	1			12,1	64,0	774,4		1½ h =			
	10					3327,5					
	22			169,4	7,7	1304,7					
	8			71,0	16,0	1120,0					
	3	½	0,0500	33,3	28,0	932,4	370	½ h = 70		4	
	1			15,6	42,8	667,7		1 h = 46			
	1			12,1	64,0	774,4		1½ h =			
	35					4799,2					
	25			180,7	7,7	1391,2					
	9			57,7	16,0	923,2					
	4	1	0,0500	31,1	28,0	870,8	336	½ h = 59		5	
	1			15,6	42,8	667,7		1 h = 35			
	1			12,1	64,0	774,4		1½ h =			
	40					4627,3					

APPENDIX VI
Cont'd

RESULTS OF RUN 4 Cont'd

ead oint	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	45			242,3	7,7	1865,7					
	15			97,3	16,0	1556,8					
	3	1½	0,0500	33,3	28,0	932,4	320	½ h = 50		5	
	1			15,6	42,8	667,7		1 h = 35			
	1			12,1	64,0	774,4		1½ h =			
	65					5797,0					
	80			323,1	7,7	2488,1					
	15			97,3	16,0	1556,8					
	5	2	0,0500	43,0	28,0	1204,2	254	½ h = 79		5	
	1			15,6	42,8	667,7		1 h = 40			
	1			12,1	64,0	774,4					
	102					6691,2					
	130			411,9	7,7	3171,9					
	18			106,7	16,0	1706,5					
	4	2½	0,0500	38,4	28,0	1075,2	328	½ h = 83		4	
	1			15,6	42,8	667,7		1 h = 45			
	1			12,1	64,0	774,4					
	154					7395,7					

APPENDIX VI
Cont'd

RESULTS OF RUN 4 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	224			529,7	8,1	4290,8					
	20			110,1	16,7	1838,7					
	5	3	0,0480	42,1	29,2	1230,6	435	½ h = 71		4	
	2			21,5	44,6	959,1		1 h = 56			
	1			11,8	71,9	848,4		1½ h =			
	252					9167,6					
	332			588,8	9,7	5711,4					
	22			105,4	20,0	2108,2					
	6	3½	0,0400	42,1	35,0	1475,0	430	½ h = 58		5	
	2			19,7	52,2	1027,3		1 h = 48			
	1			10,9	86,3	937,0		1½ h =			
	363					11258,9					
	354			610,6	9,7	5922,8					
	25			112,4	20,0	2248,0					
	10	4	0,0400	54,3	35,0	1900,5	432	½ h = 80		4	
	2			19,7	52,2	1027,3		1 h =			
	1			10,9	86,3	937,0		1½ h =			
	392					12035,6					

APPENDIX VII

RESULTS OF RUN 5 - TAPERING GS UNIT

ad int	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
- P_1	6			88,5	7,7	681,5					
- P_2	4			72,3	16,0	1156,8					
- P_3	2	0	0,0500	51,1	27,3	1395,0	332	½ h =			
- P_4	1			15,6	42,8	667,7		1 h =			
- P_5	1			13,1	60,7	795,2					
	13					4696,2					
	20			161,6	7,7	1244,3					
	9			75,4	16,0	1206,4					
	3	½	0,0500	33,3	27,3	909,1	280	½ h = 94		4	
	1			15,6	42,8	667,7		1 h = 81			
	1			13,1	60,7	795,2		1½ h = 69	1,2		
	34					4822,7					
	23			173,3	7,7	1334,1					
	10			79,5	16,0	1271,5					
	3	1	0,0500	33,3	27,3	909,1	330	½ h = 120		4	
	1			15,6	42,8	667,7		1 h = 96			
	1			13,1	60,7	795,2		1½ h = 76	1,0		
	38					4977,6					

RESULTS OF RUN 5 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	34			210,6	7,7	1621,6					
	14			94,0	16,0	1503,7					
	3	1½	0,0500	33,3	27,3	909,1	292	½ h = 114		5	
	1			15,6	42,8	667,7		1 h = 95			
	1			13,1	60,7	795,2		1½ h = 88	1,0		
	53					5497,3					
	49			252,9	7,7	1947,3					
	19			109,5	16,0	1752,6					
	4	2	0,0500	38,4	27,3	1048,3	292	½ h = 73		5	
	1			15,6	42,8	667,7		1 h = 60			
	1			13,1	60,7	795,2		1½ h = 46	1,0		
	74					6211,1					
	37			219,7	7,7	1692,0					
	17			103,6	16,0	1657,3					
	4	2½	0,0500	38,4	27,3	1048,3	280	½ h = 74		5	
	1			15,6	42,8	667,7		1 h = 48			
	1			13,1	60,7	795,2		1½ h = 40	1,0		
	60										

APPENDIX VII
Cont'd

RESULTS OF RUN 5 Cont'd

ead oint	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	30			197,9	7,7	1523,5					
	25			125,7	16,0	2011,2					
	5	3	0,0500	43,0	27,3	1174,1	440	½ h = 66		5	
	1			15,6	42,8	667,7		1 h = 56			
	1			13,1	60,7	795,2		1½ h = 51	1,0		
	62					6171,7					
	344			670,1	7,7	5159,6					
	20			112,4	16,0	1798,7					
	19	3½	0,0500	83,8	27,3	2287,7	360	½ h = 118		4	
	1			15,6	42,8	667,7		1 h = 84	1,0		
	1			13,1	60,7	795,2		1½ h =			
	385					10708,9					
	431			750,0	7,7	5774,6					
	24			123,1	16,0	1969,6					
	16	4	0,0500	76,9	27,3	2099,4	448	½ h = 90	1,0	4	
	1			15,6	42,8	667,7		1 h =			
	1			13,1	60,7	795,2		1½ h =			
	473					11306,5					

APPENDIX VIII

RESULTS OF RUN 6 - CYLINDRICAL GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Turbidity (JTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
P_0 - P_1	31			201,1	7,7	1548,6					
P_1 - P_2	7			66,5	16,0	1064,4					
P_2 - P_3	4	0	0,0500	38,4	27,3	1075,4	340				
P_3 - P_4	1			15,6	42,8	667,7					
P_4 - P_5	1			13,1	60,7	795,2					
	44					5151,3					
	59			277,4	7,7	2136,4					
	13			90,6	16,0	1449,7					
	5	½	0,0500	43,0	27,3	1174,1	310	½ h = 148		3	
	1			15,6	42,8	667,7		1 h = 120			
	1			13,1	60,7	795,2					
	79					6223,1					
	93			348,4	7,7	2682,6					
	13			90,6	16,0	1449,7					
	5	1	0,0500	43,6	27,3	1174,1	210	½ h = 137		3	
	1			15,6	42,8	667,7		1 h = 120			
	1			13,1	60,7	795,2					
	113					6769,3					

APPENDIX VIII
Cont'd

RESULTS OF RUN 6 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	219			534,6	7,7	4116,6					
	15			97,3	16,0	1556,8					
	6	1½	0,0500	47,0	27,3	1283,1	360	½ h = 140		3	
	1			15,6	42,8	667,7		1 h = 120			
	1			13,1	60,7	795,2					
	242					8419,4					
	335			661,2	7,7	5091,6					
	19			109,5	16,0	1752,6					
	7	2	0,0500	50,9	27,3	1389,0	340	½ h = 120		3	
	1			15,6	42,8	667,7		1 h = 119			
	1			13,1	60,7	795,2					
	363					9696,1					
	315			641,2	7,7	4937,1					
	21			115,2	16,0	1843,2					
	7	2½	0,0500	50,9	27,3	1389,0	280	½ h = 160		3	
	1			15,6	42,8	667,7		1 h = 136			
	1			13,1	60,7	795,2					
	345					9632,2					

RESULTS OF RUN 6 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	492			801,3	7,7	6170,1					
	19			109,5	16,0	1752,6					
	10	3	0,0500	60,8	27,3	1659,0	240	½ h = 170		3	
	1			15,6	42,8	667,7		1 h = 160			
	1			13,1	60,7	795,2					
	523					11044,6					
	685			945,5	7,7	7280,4					
	20			112,4	16,0	1798,7					
	10	3½	0,0500	60,8	27,3	1659,0	300	½ h = 60		3	
	1			15,6	42,8	667,7		1 h = 48			
	1			13,1	60,7	795,2					
	717					12201,0					
	966			1065,2	8,6	9160,9					
	21			109,2	17,8	1944,6					
	13	4	0,0450	65,8	31,1	2046,4	325	½ h = 85		3	
	1			14,8	47,5	703,0		1 h = 66			
	1			12,4	67,5	837,0					
	1002					14691,9					

RESULTS OF RUN 6 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (JTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	933			896,4	11,7	10487,7					
	22			95,7	24,3	2325,8					
	14	4½	0,0330	58,5	42,4	2480,4	300	½ h = 83	3,0	4	
	1			12,7	64,8	821,1		1 h = 30			
	1			10,6	92,0	975,2					
	971					16910,2					
	780			781,5	12,9	10081,8					
	18			82,6	26,7	2204,4					
	10	5	0,0300	47,0	46,6	2192,1	400	½ h = 41	2,0	4	
	1			12,0	71,3	855,6					
	1			10,1	101,2	1020,1					
	810					16354,0					

APPENDIX IX

RESULTS OF RUN 7 - CYLINDRICAL GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/1)	Floc quality	SS (ml/1)
P_0 - P_1	12			72,6	23,2	1683,9					
P_1 - P_2	10			66,3	23,2	1538,2					
P_2 - P_3	6	0	0,1000	48,4	27,0	1276,8	472				
P_3 - P_4	5			44,1	27,0	1192,0					
P_4 - P_5	3			34,2	27,0	923,3					
	36					6614,2					
	20			93,7	23,2	2173,9					
	25			104,8	23,2	2430,5					
	7	½	0,1000	52,2	27,0	1410,4	397	½ h = 42	12		
	7			52,2	27,0	1410,4		1 h = 38	15	5	
	5			34,2	27,0	922,7		1½ h = 33	17		
	64					8347,9					
	30			114,8	23,2	2662,7					
	33			120,4	23,2	2792,8					
	9	1	0,1000	59,2	27,0	1597,3	200	½ h = 29	7		
	10			62,3	27,0	1683,4		1 h = 25	9	5	
	3			34,2	27,0	923,6		1½ h = 21	11		
	85					9659,8					

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	42			135,8	23,2	3150,2					
	44			139,0	23,2	3225,6					
	13	1½	0,1000	71,1	27,0	1920,7	126	½ h = 24	12		
	12			68,3	27,0	1845,3		1 h = 23	13	4	
	4			39,5	27,0	1066,3		1½ h = 22	14		
	115					11208,1					
	45			140,6	23,2	3261,1					
	45			140,6	23,2	3261,1					
	13	2	0,1000	71,1	27,0	1920,7	275	½ h = 28	3		
	11			65,4	27,0	1765,6		1 h = 27	8	5	
	3			34,2	27,0	923,6		1½ h = 22	9		
	117					11132,1					
	52			151,1	23,2	3506,0					
	50			148,2	23,2	3438,4					
	13	2½	0,1000	71,1	27,0	1920,7	400	½ h = 25	8		
	12			68,3	27,0	1844,3		1 h = 19	1,1	5	
	3			34,2	27,0	923,6		1½ h = 17	1,2		
	130					11633,0					

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	67			171,5	23,2	3979,1					
	61			149,7	23,2	3472,5					
	16	3	0,1000	78,9	27,0	2129,7	320	½ h = 19	1,1		
	14			73,8	27,0	1991,9		1 h = 16	1,4	5	
	3			34,2	27,0	923,6		1½ h = 15	1,4		
	161					12496,8					
	68			172,8	23,2	4008,4					
	60			148,5	23,2	3444,5					
	18	3½	0,1000	83,7	27,0	2259,5	260	½ h = 21	1,2		
	16			73,0	27,0	1971,4		1 h = 18	1,4	5	
	3			34,2	27,0	923,6		1½ h = 18	1,5		
	165					12607,4					
	80			187,4	23,2	4348,3					
	68			158,1	23,2	3667,7					
	20	4	0,1000	88,2	27,0	2382,1	256	½ h = 22	1,2		
	16			73,0	27,0	1971,4		1 h = 19	1,3	5	
	4			39,5	27,0	1066,3		1½ h = 17	1,4		
	188					13435,8					

APPENDIX IX
Cont'd

RESULTS OF RUN 7 Cont'd

Head	loss	Time	Flow	G	t	Gt	Turbidity (NTU)		Floc amount	Floc	SS
Point	(mm)	(h)	(x 10^{-3} m^3/s)	(s^{-1})	(s)		Initial	Final	(ml/l)	quality	(ml/l)
	89			197,7	23,2	4585,7					
	73			172,3	23,2	3996,4					
	20	4½	0,1000	88,2	27,0	2382,1	252	½ h = 22	1,2		
	17			75,2	27,0	2031,7		1 h = 18	1,3	5	
	4			39,5	27,0	1066,3		1½ h = 17	1,5		
	203					14062,2					
	100			209,6	23,2	4861,8					
	79			179,2	23,2	4158,4					
	23	5	0,1000	94,6	27,0	2553,8	226	½ h = 19	2,0		
	20			81,6	27,0	2202,3		1 h = 18	2,3	5	
	4			39,5	27,0	1066,3		1½ h = 17	2,3		
	226					14842,6					
	110			219,2	23,2	5085,4					
	85			185,9	23,2	4312,4					
	21	5½	0,1000	90,4	27,0	2440,6	276	½ h = 22	2,0		
	18			77,4	27,0	2090,1		1 h = 14	2,0	5	
	4			39,5	27,0	1066,3		1½ h = 12	1,9		
	238					14994,8					

APPENDIX IX
Cont'd

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	135			242,8	23,2	5633,0					
	96			197,6	23,2	4583,5					
	25	6	0,1000	98,6	27,0	2663,1	278	½ h = 14	2,0		
	20			81,6	27,0	2202,3		1 h = 14	2,1	5	
	5			44,2	27,0	1192,4		1½ h = 13	2,5		
	281					16274,3					
	144			250,8	23,2	5817,7					
	99			200,7	23,2	4655,4					
	25	6½	0,1000	98,6	27,0	2663,1	300	½ h = 14	2,0		
	22			85,6	27,0	2310,7		1 h = 14	2,1	5	
	4			39,5	27,0	1066,3		1½ h = 14	2,5		
	294					16513,2					
	158			275,2	23,2	6384,6					
	100			201,7	23,2	4679,7					
	25	7	0,1000	98,6	27,0	2663,1	260	½ h = 20	3,0		
	22			85,6	27,0	2310,7		1 h = 13	3,0		
	5			44,2	27,0	1192,4		1½ h = 11	3,0		
	310					17230,5					

RESULTS OF RUN 7 Cont'd

Point	Head loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	170			285,0	23,2	6623,6					
	105			206,7	23,2	4795,0					
	26	7½	0,1000	100,6	27,0	2714,9	320	½ h = 22	4,5		
	22			85,6	27,0	2310,7		1 h = 21	4,5	5	
	4			39,5	27,0	1066,3		1½ h = 16			
	327					17510,5					
	167			283,0	23,2	6564,9					
	87			188,2	23,2	4366,2					
	23	8	0,1000	94,6	27,0	2554,2	224	½ h = 29	1,0		
	20			83,4	27,0	2252,7		1 h = 25	3,5	5	
	4			39,5	27,0	1066,3		1½ h =			
	301					16804,3					
	210			303,6	23,2	7043,5					
	90			198,8	23,2	4612,2					
	22	8½	0,1000	92,6	27,0	2500,2	288	½ h = 26	3,5	5	
	19			82,6	27,0	2330,2		1 h =			
	4			39,5	27,0	1066,3		1½ h =			
	345					17552,2					

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity Initial	(NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	184			262,4	23,2	6087,1					
	56			144,7	23,2	3358,1					
	15	9	0,1000	74,9	27,0	2022,1	360	½ h =			
	15			74,9	27,0	2022,1		1 h =			
	4			39,5	27,0	1066,3		1½ h =			
	274					14555,7					
	188			264,2	23,2	6129,4					
	70			161,8	23,2	3753,3					
	18	9½	0,1000	82,0	27,0	2215,3	300	½ h = 34	1,3		
	18			82,0	27,0	2215,3		1 h = 29	1,5	4	
	4			39,5	27,0	1066,3		1½ h = 23	1,7		
	298					15379,6					
	260			310,7	23,2	7208,2					
	96			189,5	23,2	4396,0					
	23	10	0,1000	92,7	27,0	2502,7	280	½ h = 33	1,0		
	22			90,7	27,0	2447,7		1 h = 32	1,5	4	
	5			43,3	27,0	1168,2		1½ h = 32	2,0		
	406					17722,8					

ad int	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	343			356,9	23,2	8279,2					
	114			206,0	23,2	4778,2					
	27	10½	0,1000	98,3	27,0	2654,7	400	½ h = 32	1,0		
	25			94,6	27,0	2553,2		1 h = 26	1,1	4	
	5			43,3	27,0	1168,2		1½ h = 22	1,3		
	514					19433,5					
	350			360,5	23,2	8364,1					
	106			198,6	23,2	4608,5					
	26	11	0,1000	96,5	27,0	2604,5	320	½ h = 37	1,0		
	25			94,6	27,0	2553,2		1 h = 35	1,5	4	
	6			47,4	27,0	1280,7		1½ h = 29	1,6		
	513					19411,0					
	475			420,0	23,2	9743,3					
	111			203,2	23,2	4714,9					
	26	11½	0,1000	96,5	27,0	2604,5	280	½ h = 34	0,5		
	25			94,6	27,0	2553,0		1 h = 30	0,9	4	
	5			47,4	27,0	1280,7		1½ h = 27	1,5		
	642					20896,4					

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/1)	Floc quality	SS (ml/1)
	570			460,1	23,2	10674,3					
	127			217,4	23,2	5042,6					
	28	12	0,1000	100,1	27,0	2703,9	230	½ h = 37	0,7		
	26			96,5	27,0	2604,5		1 h = 26	1,0	4	
	5			47,4	27,0	1280,7		1½ h = 20	1,8		
	756					22306,0					
	614			477,5	23,2	11078,7					
	135			224,1	23,2	5200,1					
	32	12½	0,1000	107,0	27,0	2889,3	288	½ h = 36	1,0		
	29			101,9	27,0	2751,7		1 h = 33	1,2	4	
	6			51,9	27,0	1402,0		1½ h = 33	1,5		
	816					23321,8					
	624			471,1	28,7	13520,6					
	140			223,1	28,7	6403,0					
	31	13	0,0810	98,9	32,6	3217,6	284	½ h = 34	0,5		
	27			92,3	32,6	3009,0		1 h = 32	0,7	4	
	6			43,5	32,6	1418,1		1½ h = 20	1,0		
	828					27568,3					

APPENDIX IX
Cont'd

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	680			539,5	27,7	14944,2					
	159			264,2	27,7	7318,3					
	32	13½	0,0840	111,7	31,4	3507,4	248	½ h = 28	0,5		
	29			106,3	31,4	3337,8		1 h = 22	0,6	4	
	6			48,4	31,4	1519,8		1½ h = 16	1,5		
	906					30627,5					
	720			555,1	36,9	20483,2					
	154			260,0	36,9	9594,0					
	30	14	0,0630	108,2	41,9	4533,6	320	½ h = 34	0,3		
	25			98,7	41,9	4135,5		1 h = 34	0,6	3	
	5			44,2	41,9	1852,0		1½ h = 31	0,8		
	934					40598,3					
	687			542,2	52,8	28628,2					
	131			240,0	52,8	12672,0					
	25	14½	0,0440	98,8	59,9	5918,1	336	½ h = 30	0,4		
	20			88,3	59,9	5289,2		1 h = 30	0,5	3	
	4			39,5	59,9	2366,1		1½ h =			
	867					54873,6					

RESULTS OF RUN 7 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	736			311,4	77,5	24133,5					
	149			140,1	77,5	10857,8					
	27	15	0,0300	56,2	87,9	4940,0	308	½ h = 40	0,3	3	
	21			49,6	87,9	4359,8		1 h =			
	3			18,7	87,9	1643,7		1½ h =			
	936					45934,8					

APPENDIX X

RESULTS OF RUN 8 - CYLINDRICAL GS UNIT

ead oint	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$0 - P_1$	60			229,5	11,6	2667,1					
$1 - P_2$	52			213,7	11,6	2493,6					
$2 - P_3$	17	0	0,2000	115,1	13,2	1519,6	320	½ h =			
$3 - P_4$	17			115,1	13,2	1519,6		1 h =			
$4 - P_5$	5			62,4	13,2	824,1		1½ h =			
	151					9024,0					
	155			368,9	11,6	4286,7					
	60			229,5	11,6	2667,1					
	20	½	0,2000	124,9	13,2	1648,3	210	½ h = 40	0,5		
	20			124,9	13,2	1648,3		1 h = 30	0,6	4	
	5			62,4	13,2	824,1		1½ h = 30	0,7		
	260					11074,5					
	478			579,4	14,5	8401,9					
	68			218,6	14,5	3169,0					
	21	1	0,1600	114,4	16,5	1659,5	288	½ h = 29	0,5		
	18			106,0	16,5	1536,4		1 h = 25	0,7	4	
	5			55,8	16,5	809,7		1½ h = 22	0,9		
	590					15576,5					

APPENDIX X
Cont'd

RESULTS OF RUN 8 Cont'd

Head Point	loss (mm)	Time (h)	Flow $(\times 10^{-3}\ m^3/s)$	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/1)	Floc quality	SS (ml/1)
	630			585,6	18,7	10950,7					
	67			191,0	18,7	3571,3					
	20	1½	0,1240	98,3	21,3	2094,3	241	½ h = 30	0,5		
	16			87,9	21,3	1873,2		1 h = 29	0,7	4	
	4			44,0	21,3	936,6		1½ h = 22	0,9		
	737					19426,1					
	738			623,5	19,4	12096,4					
	68			189,3	19,4	3671,8					
	18	2	0,1200	91,8	22,0	2018,7	200	½ h = 36	0,5	4	
	14			80,9	22,0	1780,4		1 h = 20	0,9		
	3			37,5	22,0	824,1		1½ h = 20			
	841					20391,4					
	779			539,2	27,3	14719,0					
	73			165,0	27,3	4505,8					
	17	2½	0,0850	75,1	31,0	2326,6	260	½ h = 24	0,5	4	
	13			65,6	31,0	2034,6		1 h =			
	3			31,5	31,0	977,4		1½ h =			
	885					24563,4					

APPENDIX XI

RESULTS OF RUN 9 - CYLINDRICAL GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	12			72,6	23,2	1683,9					
$P_1 - P_2$	10			66,3	23,2	1537,2					
$P_2 - P_3$	11	0	0,1000	69,5	23,2	1612,2	248				
$P_3 - P_4$	5			44,1	26,4	1165,5					
$P_4 - P_5$	5			44,1	26,4	1165,5					
	43					7164,3					
	22			98,3	23,2	2280,0					
	14			78,4	23,2	1818,8					
	18	½	0,1000	88,9	23,2	2062,3	298	½ h = 54	0	3	
	6			48,4	26,4	1276,8		1 h = 47	0,1		
	8			55,8	26,4	1474,3		1½ h = 21	0,5		
	68					8912,2					
	35			124,0	23,2	2876,8					
	19			91,3	23,2	2118,9					
	22	1	0,1000	98,3	23,2	2280,0	366	½ h = 26	0	3	
	8			55,8	26,4	1474,3		1 h = 17	0,1		
	10			62,4	26,4	1648,3		1½ h = 16	0,5		
	94					10398,3					

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU)		Floc amount (ml/l)	Floc quality	SS (ml/l)
							Initial	Final			
	50			148,2	23,2	3437,2					
	28			110,9	23,2	2572,2				4	
	30	1½	0,1000	114,8	23,2	2662,5	560	½ h = 43			
	12			68,4	26,4	1805,6		1 h = 40			
	11			65,5	26,4	1728,7		1½ h = 33			
	131					12206,2					
	67			171,5	23,2	3978,9					
	35			124,0	23,2	2875,8					
	38	2	0,1000	129,2	23,2	2996,5	324	½ h = 47	1,0	5	
	12			68,4	26,4	1805,6		1 h = 36	1,3		
	13			71,2	26,4	2018,0		1½ h = 29	1,3		
	165					13536,1					
	93			202,1	23,2	4687,8					
	42			135,8	23,2	3150,6					
	45	2½	0,1000	140,6	23,2	3260,9	320	½ h = 40	0,5	5	
	14			73,9	26,4	1950,3		1 h = 32	0,8		
	15			76,5	26,4	2018,0		1½ h = 27	0,8		
	209					15067,6					

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	127			236,1	23,2	5478,1					
	52			151,1	23,2	3505,3					
	53	3	0,1000	152,5	23,2	3538,9	350	½ h = 28	1,2	5	
	15			76,5	26,4	2019,6		1 h = 22	1,2		
	17			81,4	26,4	2149,1		1½ h = 17	1,3		
	264					16691,0					
	160			265,0	23,2	6148,7					
	60			162,3	23,2	3765,3					
	60	3½	0,1000	162,3	23,2	3765,3	348	½ h = 21	0,7	5	
	16			79,0	26,4	2085,6		1 h = 15	1,2		
	18			83,8	26,4	2211,4		1½ h = 14	1,5		
	314					17976,3					
	192			290,3	23,2	6735,6					
	65			168,9	23,2	3919,1					
	65	4	0,1000	168,9	23,2	3919,1	234	½ h = 24	0,8	5	
	16			79,0	26,4	2085,6		1 h = 21	1,0		
	20			93,7	26,4	2473,7		1½ h = 15	1,2		
	358					19133,1					

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	235			321,2	23,2	7451,8					
	67			171,5	23,2	3979,0					
	78	4½	0,1000	185,0	23,2	4293,1	370	½ h = 25	1,0	5	
	20			93,7	26,4	2473,7		1 h = 20	1,2		
	22			94,6	26,4	2497,0		1½ h = 17	1,3		
	422					20694,6					
	290			356,8	23,2	8278,0					
	75			181,5	23,2	4209,7					
	80	5	0,1000	187,4	23,2	4347,8	299	½ h = 18	0,9	5	
	20			93,7	26,4	2473,7		1 h = 13	1,2		
	23			94,7	26,4	2499,8		1½ h = 11	1,3		
	488					21809,0					
	340			386,3	23,2	8963,2					
	80			187,4	23,2	4347,8					
	84	5½	0,1000	192,0	23,2	4455,2	256	½ h = 20	1,4	5	
	20			93,7	26,4	2473,7		1 h = 16	1,5		
	24			96,7	26,4	2552,8		1½ h = 14	1,6		
	548					22792,7					

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	405			421,7	23,2	9782,6					
	50			148,2	23,2	3437,2					
	50	6	0,1000	148,2	23,2	3437,2	251	½ h = 25	0,9	5	
	18			83,8	26,4	2211,4		1 h = 23	1,0		
	20			93,7	26,4	2473,7		1½ h = 21	1,1		
	543					21342,1					
	605			515,4	23,2	11956,5					
	62			167,6	23,2	3888,8					
	61	6½	0,1000	163,6	23,2	3796,6	504	½ h = 30	0,4	5	
	18			83,8	26,4	2211,4		1 h = 26	0,5		
	20			93,7	26,4	2473,7		1½ h = 22	0,6		
	766					24327,0					
	740			493,6	31,0	15301,9					
	67			148,5	31,0	4604,3					
	63	7	0,0750	144,0	31,0	4464,8	344	½ h = 28	0,5	4	
	17			70,5	35,2	2481,6		1 h = 23	0,7		
	18			77,0	35,2	2710,0		1½ h = 21	0,8		
	905					29562,6					

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	693			480,9	30,6	14714,0					
	75			158,2	30,6	4840,6					
	70	7½	0,0760	152,8	30,6	4676,4	318	½ h = 30	0,7	4	
	17			71,0	47,1	2498,1		1 h = 23	0,9		
	17			71,0	47,1	2498,1		1½ h = 21	1,0		
	872					29227,2					
	765			433,7	41,5	17997,4					
	70			131,2	41,5	5444,1					
	61	8	0,0560	122,5	41,5	5082,1	344	½ h = 22	0,5	4	
	16			59,1	47,1	2783,6		1 h = 20	0,6		
	15			57,2	47,1	2695,2		1½ h = 18	0,7		
	927					34002,4					
	770			411,1	46,5	19116,2					
	70			124,0	46,5	5764,0					
	60	8½	0,0500	114,8	46,5	5336,4	456	½ h = 30	0,6	4	
	14			52,2	52,8	2758,1		1 h = 24	0,8		
	14			52,2	52,8	2758,1		1½ h = 20	0,8		
	928					35732,8					

APPENDIX XI Cont'd

RESULTS OF RUN 9 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	829			371,9	61,1	22722,0					
	65			104,1	61,1	6362,5					
	53	9	0,0380	94,0	61,1	5745,2	600	½ h = 22	0,4	4	
	10			38,5	69,4	2671,0		1 h = 17	0,5		
	10			38,5	69,4	2671,0		1½ h = 17	0,6		
	967					40171,7					
	843			327,6	80,1	26241,1					
	63			89,6	80,1	7173,6					
	47	9½	0,0290	77,4	80,1	6196,1	520	½ h = 18	0,2	4	
	8			30,1	91,0	2736,6		1 h = 17	0,5		
	8			30,1	91,0	2736,6		1½ h =			
	969					45084,0					

APPENDIX XII

RESULTS OF RUN 10 - CYLINDRICAL GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	25			104,8	23,2	2430,5					
$P_1 - P_2$	14			78,4	23,2	1818,8					
$P_2 - P_3$	15	0	0,1000	81,1	23,2	1882,7	496	½ h =			
$P_3 - P_4$	4			39,5	26,4	1042,5		1 h =			
$P_4 - P_5$	5			44,1	26,4	1165,5		1½ h =			
	63					8340,0					
	41			134,2	23,2	3112,6					
	16			83,8	23,2	1944,4					
	19	½	0,1000	91,3	23,2	2118,9	496	½ h = 43	0,1	3	
	6			48,4	26,4	1276,8		1 h = 38	0,1		
	7			52,2	26,4	1379,1		1½ h = 36	0,1		
	89					9831,8					
	86			194,3	23,2	4507,9					
	24			102,6	23,2	2381,4					
	25	1	0,1000	104,8	23,2	2430,5	392	½ h = 40	0,1	3	
	9			59,2	26,4	1563,7		1 h = 37	0,2		
	9			59,2	26,4	1563,7		1½ h = 33	0,2		
	153					12447,2					

RESULTS OF RUN 10 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	130			238,9	23,2	5542,4					
	28			110,9	23,2	2572,2					
	29	1½	0,1000	112,8	23,2	2617,7	310	½ h = 27	0,1	3	
	9			59,2	26,4	1563,7		1 h = 26	0,1		
	9			59,2	26,4	1563,7		1½ h = 20	0,2		
	205					13859,7					
	172			274,8	23,2	6375,1					
	22			98,3	23,2	2280,0					
	20	2	0,1000	93,7	23,2	2173,9	360	½ h = 24	0,1	3	
	5			44,1	26,4	1165,5		1 h = 22	0,1		
	6			48,4	26,4	1276,8		1½ h = 21	0,2		
	225					13271,3					
	205			300,0	23,2	6959,9					
	50			148,2	23,2	3437,0					
	55	2½	0,1000	155,4	23,2	3605,0	340	½ h = 19	1,4	4	
	18			83,8	26,4	2211,4		1 h = 13	1,5		
	18			83,8	26,4	2211,4		1½ h = 12	1,5		
	346					18424,7					

RESULTS OF RUN 10 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	245			328,0	23,2	7608,7					
	54			154,0	23,2	3572,1					
	57	3	0,1000	158,2	23,2	3670,0	300	½ h = 15	1,0	4	
	15			76,5	26,4	2018,7		1 h = 13	1,1		
	15			76,5	26,4	2018,7		1½ h = 10	1,1		
	386					18888,2					

APPENDIX XIII

RESULTS OF RUN 11 - CYLINDRICAL GS UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	25			152,9	11,0	1682,3					
$P_1 - P_2$	12			106,0	11,3	1197,8					
$P_2 - P_3$	5	0	0,2400	67,0	11,3	757,1	340				
$P_3 - P_4$	2			42,4	11,5	487,3					
$P_4 - P_5$	1			30,0	11,5	344,6					
	45					4469,1					
	45			203,9	11,1	2263,3					
	18			126,3	11,4	1440,1					
	8	½	0,2370	84,2	11,4	960,1	168	½ h = 10	0	3	
	3			51,6	11,7	603,4		1 h = 9	0,3		
	2			42,1	11,7	492,7		1½ h = 8	0,5		
	76					5759,6					
	55			225,4	11,1	2502,1					
	21			136,4	11,4	1555,5					
	8	1	0,2370	84,2	11,4	960,1	200	½ h = 23	0,1	3	
	3			51,6	11,7	603,4		1 h = 19	0,9		
	2			42,1	11,7	492,7		1½ h = 15	1,0		
	89					6113,8					

RESULTS OF RUN 11 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	80			271,9	11,7	3180,8					
	29			160,3	12,0	1924,1					
	9	1½	0,2250	89,3	12,0	1071,6	300	½ h = 25	0,5	3	
	4			58,0	12,3	713,7		1 h = 23	0,6		
	4			58,0	12,3	713,7		1½ h = 16	0,7		
	126					7603,9					
	107			302,9	12,0	3634,8					
	34			167,3	12,3	2057,5					
	10	2	0,2200	90,7	12,3	1115,8	272	½ h = 25	0	4	
	5			64,1	12,6	808,7		1 h = 15	0,1		
	4			57,4	12,6	722,9		1½ h = 10	1,5		
	160					8339,2					
	147			355,1	12,0	4260,7					
	34			167,3	12,3	2057,5					
	11	2½	0,2200	95,1	12,3	1170,3	240	½ h = 35	0,1	4	
	5			64,1	12,6	808,2		1 h = 25	1,1		
	3			49,7	12,6	626,1		1½ h = 21	1,3		
	200					8922,8					

Head Point	loss (mm)	Time (h)	Flow ($\times 10^{-3}$ m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	211			438,7	11,3	4957,3					
	41			189,4	11,5	2178,6					
	12	3	0,2340	102,5	11,5	1178,6	278	½ h = 28	0,6	4	
	6			72,5	11,8	855,1		1 h = 22	0,8		
	3			51,2	11,8	604,7		1½ h = 19	0,9		
	273					9774,3					
	296			512,9	11,6	5949,6					
	46			198,1	11,8	2337,6					
	16	3½	0,2280	116,8	11,8	1378,4	200	½ h = 21	0,6	5	
	7			77,3	12,1	934,9		1 h = 18	0,7		
	4			58,4	12,1	706,7		1½ h = 15	0,8		
	369					11307,2					
	375			574,8	11,7	6724,9					
	46			197,2	12,0	2366,4					
	16	4	0,2260	116,3	12,0	1395,6	344	½ h = 26	0,1	5	
	7			76,9	12,3	946,6		1 h = 19	1,2		
	4			58,2	12,3	715,3		1½ h = 16	2,0		
	448					12148,8					

RESULTS OF RUN 11 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	434			581,7	13,2	7678,3					
	42			177,3	13,5	2395,6					
	15	4½	0,2000	105,9	13,5	1430,1	284	½ h = 50	1,5	4	
	6			67,0	13,8	924,6		1 h = 35	1,5		
	4			54,7	13,8	754,9		1½ h = 24	1,9		
	501					13183,5					
	525			620,4	13,5	8375,6					
	45			181,6	13,8	2506,6					
	15	5	0,1960	104,9	13,8	1447,2	260	½ h = 32	0,7	4	
	6			66,3	14,1	935,2		1 h = 23	1,1		
	4			54,2	14,1	763,6		1½ h = 22	1,2		
	595					14028,2					
	582			621,0	15,5	9625,5					
	47			172,9	15,9	2749,1					
	17	5½	0,1700	104,0	15,9	1653,2	368	½ h = 24	0,5	4	
	5			56,4	16,3	919,1		1 h = 23	0,6		
	4			50,4	16,3	822,1		1½ h = 20	1,0		
	655					15769,0					

RESULTS OF RUN 11 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml l
	670			604,7	18,8	11368,1					
	40			144,7	19,3	2793,4					
	16	6	0,1400	90,6	19,3	1748,3	316	½ h = 85	0,1	4	
	5			51,2	19,7	1008,1		1 h = 49	3,0		
	4			39,6	19,7	780,8		1½ h = 25	4,0		
	935					17698,7					

APPENDIX XIV

RESULTS OF RUN 12 - TAPERING PERSPEX UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
P_0 - P_1	25			255,4	3,9	996,2					
P_1 - P_2	7			94,0	8,0	752,2					
P_2 - P_3	4	0	0,1000	44,0	13,7	602,4	400	½ h =			
P_3 - P_4	3			38,1	20,9	796,3		1 h =			
P_4 - P_5	1			18,5	29,7	548,0		1½ h =			
	40					3695,1					
	20			228,5	3,9	891,1					
	10			112,4	8,0	899,2					
	6	½	0,1000	53,9	13,7	738,4	400	½ h = 55	2,5		
	2			31,1	20,7	649,8		1 h = 30	3,5		
	1			18,5	29,7	548,0		1½ h = 28	6,0		
	39					3762,5					
	20			228,5	3,9	891,1					
	13			128,1	8,0	1025,0					
	5	1	0,1000	49,2	13,7	674,0	440	½ h = 67	1,5		
	2			31,1	20,9	649,8		1 h = 44	2,1		
	1			18,5	29,7	548,0		1½ h = 27	4,0		
	41					3787,9					

RESULTS OF RUN 12 Cont'd

Head	loss	Time	Flow	G	t	Gt	Turbidity (NTU)		Floc amount	Floc	SS
Point	(mm)	(h)	(x 10^{-3} m^3/s)	(s^{-1})	(s)		Initial	Final	(ml/l)	quality	(ml/l)
	20			228,5	3,9	891,1					
	13			128,1	8,0	1025,0					
	5	1½	0,1000	49,2	13,7	674,0	600	½ h = 60	2,0		
	2			31,1	20,9	649,8		1 h = 37	2,5		
	1			18,5	29,7	548,0		1½ h = 26	5,0		
	41					3787,9					
	22			239,6	3,9	934,6					
	20			158,9	8,0	1271,5					
	18	2	0,1000	115,3	13,7	1579,8	600	½ h = 55	2,5		
	5			49,2	20,9	1027,5		1 h = 30	3,0		
	1			18,5	29,7	548,0		1½ h = 24	4,0		
	66					5361,4					
	20			228,5	3,9	891,1					
	24			174,1	8,0	1392,8					
	20	2½	0,1000	133,2	13,7	1824,2	500	½ h = 60	2,0		
	2			31,1	20,9	649,8		1 h = 30	2,5		
	1			18,5	29,7	548,0		1½ h = 24	3,0		
	67					5305,9					

RESULTS OF RUN 12 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	22			239,6	3,9	934,6					
	18			150,8	8,0	1206,2					
	17	3	0,1000	116,7	13,7	1599,2	510	½ h = 65	1,0		
	5			49,2	20,9	1027,5		1 h = 32	1,5		
	1			18,5	29,7	548,0		1½ h = 25	2,0		
	63					5315,5					
	20			239,6	3,9	934,6					
	25			177,7	8,0	1421,5					
	10	3½	0,1000	85,9	13,7	1177,5	520	½ h = 88	0,8		
	2			31,1	20,9	649,8		1 h = 50	3,0		0,3
	1			18,5	29,7	548,0		1½ h = 25	5,5		
	58					4731,4					
	25			255,4	3,9	996,2					
	20			158,9	8,0	1271,5					
	17	4	0,1000	112,1	13,7	1535,3	400	½ h = 50	1,3		
	3			38,1	20,9	795,9		1 h = 34	2,0		0,5
	1			18,5	29,7	548,0		1½ h = 20	2,5		
	66					5146,9					

RESULTS OF RUN 12 Cont'd

Point	Head loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	35			302,3	3,9	1178,8					
	20			158,9	8,0	1271,5					
	25	4½	0,1000	135,9	13,7	1861,8	420	½ h = 59	1,7		
	5			49,2	20,9	1027,5		1 h = 36	2,0		0,5
	2			26,1	29,7	776,0		1½ h = 32	2,0		
	87					6115,6					
	50			361,3	3,9	1408,9					
	25			177,7	8,0	1421,5					
	30	5	0,1000	148,9	13,7	2039,5	425	½ h = 55	1,3		
	5			49,2	20,9	1027,5		1 h = 35	1,5		2,5
	4			36,9	29,7	1096,0		1½ h = 30	2,0		
	114					6993,4					
	60			395,7	3,9	1543,4					
	30			194,7	8,0	1557,2					
	32	5½	0,1000	153,8	13,7	2106,4	425	½ h = 60	1,5		
	13			79,3	20,9	1656,7		1 h = 32	2,0		3,0
	3			32,0	29,7	949,2		1½ h = 30	2,5		
	138					7812,9					

APPENDIX XIV
Cont'd

RESULTS OF RUN 12 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/1)	Floc quality	SS (ml/1)
	68			421,3	3,9	1643,1					
	25			158,9	8,0	1271,5					
	35	6	0,1000	160,8	13,7	2202,9	500	½ h = 53	0,8		
	30			120,4	20,9	2516,8		1 h = 41	1,5		2,5
	6			45,2	29,7	1342,3		1½ h = 28	1,6		
	164					8976,6					
	68			421,3	3,9	1643,1					
	24			174,1	8,0	1392,8					
	38	6½	0,1000	167,5	13,7	2295,4	540	½ h = 53	1,9		
	30			120,4	20,7	2516,8		1 h = 41	2,0		10
	6			45,2	29,7	1342,3		1½ h = 28	2,5		
	166					9190,4					
	55			378,9	3,9	1477,7					
	26			181,2	8,0	1449,7					
	40	7	0,1000	171,9	13,7	2355,0	560	½ h = 67	1,2		
	30			120,4	20,7	2516,8		1 h = 53	1,5		15
	8			52,2	29,7	1550,0		1½ h = 41	1,7		
	159					9349,2					

APPENDIX XIV
Cont'd

RESULTS OF RUN 12 Cont'd

Head loss		Time	Flow	G	t	Gt	Turbidity (NTU)		Floc amount	Floc	SS
Point	(mm)	(h)	(x 10^{-3} m^3/s)	(s^{-1})	(s)		Initial	Final	(ml/l)	quality	(ml/l)
	85			471,0	3,9	1837,0					
	28			188,1	8,0	1504,4					
	40	7½	0,1000	171,9	13,7	2355,0	600	½ h = 54	2,5		
	37			133,7	20,7	2795,0		1 h = 38	2,6		0,5
	2			26,1	29,7	776,0		1½ h = 36	2,7		
	192					9267,4					
	60			395,7	3,9	1543,4					
	33			204,2	8,0	1633,2					
	47	8	0,1000	186,3	13,7	2552,8	432	½ h = 52	2,5		
	37			133,7	20,7	2795,0		1 h = 38	2,6		0,5
	2			26,1	29,7	776,0		1½ h = 28	2,7		
	179					9300,4					
	73			436,5	3,9	1702,4					
	30			194,7	8,0	1557,2					
	37	8½	0,1000	165,3	13,7	2265,0	600	½ h = 73	8,5		
	38			135,5	20,7	2832,5		1 h = 59	8,5		15
	12			63,9	29,7	1898,4		1½ h = 44	8,5		
	190					10252,5					

RESULTS OF RUN 12 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	73			436,5	3,9	1702,4					
	28			188,1	8,0	1504,4					
	40	9	0,1000	171,9	13,7	2355,0	600	½ h = 70	8,0		
	45			147,5	20,7	3082,4		1 h = 47	8,0		0,6
	16			73,8	29,7	2192,0		1½ h = 30	9,0		
	202					10836,2					
	70			427,0	3,9	1667,0					
	28			188,1	8,0	1504,4					
	38	9½	0,1000	167,5	13,7	2295,4	600	½ h = 47	1,5		0,7
	40			139,0	20,7	2906,1		1 h = 45	1,7		
	22			86,5	29,7	2570,4		1½ h = 31	1,8		
	198					10943,3					

Back wash done

APPENDIX XV

RESULTS OF RUN 13 - TAPERING PERSPEX UNIT

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
$P_0 - P_1$	15			197,9	3,9	771,7					
$P_1 - P_2$	6			87,1	8,0	696,4					
$P_2 - P_3$	1	0	0,1000	27,2	13,7	372,4	520				
$P_3 - P_4$	1			20,0	20,9	459,5					
$P_4 - P_5$	1			18,5	29,7	548,0					
	24					2848,0					
	15			197,9	3,9	771,7					
	6			87,1	8,0	696,4					
	1	½	0,1000	27,2	13,7	372,4	520	½ h = 61	3,0		
	1			20,0	20,9	459,5		1 h = 33	6,5		7,5
	1			18,5	29,7	548,0		1½ h = 29	7,0		
	24					2848,0					
	20			228,5	3,9	891,1					
	6			87,1	8,0	696,4					
	2	1	0,1000	38,4	13,7	526,1	600	½ h = 86	3,0		
	1			20,0	20,9	459,5		1 h = 51	4,0		0,5
	1			18,5	29,7	548,0		1½ h = 37	4,5		
	30					3121,1					

RESULTS OF RUN 13 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	23			245,0	3,9	955,6					
	8			100,5	8,0	804,2					
	2	1½	0,1000	38,4	13,7	526,1	400	½ h = 148	4,0		
	2			31,1	20,9	649,8		1 h = 74	4,5		0,5
	1			18,5	29,7	548,0		1½ h = 47	5,0		
	36					3483,7					
	30			279,8	3,9	1091,4					
	10			112,4	8,0	899,2					
	3	2	0,1000	47,1	13,7	645,0	400	½ h = 150	0,5	0,5	
	2			31,1	20,9	649,8		1 h = 120	2,5	2,5	0,8
	1			18,5	29,7	548,5		1½ h = 70	3,5	3,5	
	46					3833,9					
	32			289,0	3,9	1127,1					
	37			216,2	8,0	1729,4					
	1	2½	0,1000	27,2	13,7	372,4	400	½ h = 75	1,7	1,7	
	1			31,1	20,9	649,8		1 h = 47	2,0	2,0	0,5
	1			18,5	29,7	548,5		1½ h = 32	2,5	2,5	
	72					4427,2					

APPENDIX XV
Cont'd

RESULTS OF RUN 13 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	54			375,4	3,9	1464,2					
	10			112,4	8,0	899,2					
	2	3	0,1000	38,4	13,7	526,1	460	½ h = 130	0,7	0,7	
	2			31,1	20,9	649,8		1 h = 48	4,0	4,0	15
	1			18,5	29,7	548,5		1½ h = 26	6,5	6,5	
	69					4087,8					
	61			399,0	3,9	1556,2					
	12			123,1	8,0	984,9					
	3	3½	0,1000	47,1	13,7	645,0	460	½ h = 70	3,0	3,0	
	3			38,1	20,9	795,9		1 h = 63	4,0	4,0	8
	1			18,5	29,7	548,5		1½ h = 30	6,0	6,0	
	80					4530,5					
	68			421,3	3,9	1643,1					
	16			142,2	8,0	1137,3					
	10	4	0,1000	86,0	13,7	1177,5	384	½ h = 136	1,0	1,0	
	7			58,2	20,9	1215,7		1 h = 60	3,0	3,0	0,6
	2			26,1	29,7	775,0		1½ h = 27	6,0	6,0	
	103					5948,6					

RESULTS OF RUN 13 Cont'd

Head Point	loss (mm)	Time (h)	Flow (x 10^{-3} m^3/s)	G (s^{-1})	t (s)	Gt	Turbidity (NTU) Initial	Turbidity (NTU) Final	Floc amount (ml/l)	Floc quality	SS (ml/l)
	68			421,3	3,9	1643,1					
	16			142,2	8,0	1137,3					
	10	4½	0,1000	86,0	13,7	1177,5	400	½ h = 56	2,0	2,0	
	7			58,2	20,9	1215,7		1 h = 30	3,0	3,0	1,8
	2			26,1	29,7	775,0		1½ h =			
	103					5948,6					
	86			473,8	3,9	1847,8					
	20			158,9	8,0	1271,5					
	23	5	0,1000	130,4	13,7	1785,8	420	½ h = 74	2,5		
	8			62,2	20,9	1299,7		1 h =			
	5			41,2	29,7	1225,4		1½ h =			
	142					7430,2					

WORTH ANALYSIS

The data used here has partly been extracted from the Ministry of Water Development (MoWD) Water Design Manual 1984 and partly form tender rates of some water contracts. These costs have been divided into:

1) capital cost,
2) operation cost,
3) maintenance cost.

The present worth analysis has been employed for cost comparison. The following data were got from MoWD 1984:

a) life of UGBF is 10 years and maintenance cost is 2 %,
b) life of coagulation-flocculation basin is 30 years and maintenance cost is 1 %,
c) annual interest on funds i = 10 %.

The treatment capacity is 250 m^3/day.

From the experiments already conducted, the dosage for UGBF could be as low as 13 mg/l and the dosage for the conventional system is 72 mg/l.

Alternative A: UGBF

Capital cost initially = 4600,00 KES
Maintenance cost = 2 % of 4600 = 92,00 KES per annum
Operation cost
Amount of alum required = 13 (mg/l) x 250000 mg
= 3,25 kg/d
= 365 x 3,25 kg/year
= 365 x 3,25 x 5,60
= 6643,00 KES per annum

The UGBF unit would be renewed after every 10 years.

Capital cost present worth = 4600,00 KES

$$\text{Maintenance cost} = 92\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = 92\left[\frac{1,1^{30} - 1}{0,1(1,1)^{30}}\right] = 867,00 \text{ KES}$$

$$\text{Capital renewal} = 4600\left[\frac{1,1^{10} - 1}{0,1(1,1)^{10}} + \frac{1,1^{20} - 1}{0,1(1,1)^{20}} + \frac{1,1^{30} - 1}{0,1(1,1)^{30}}\right] = 110796,00 \text{ KES}$$

$$\text{Operation cost} = 6643\left[\frac{1,1^{10} - 1}{0,1(1,1)^{10}}\right] = 40818,00 \text{ KES}$$

Alternative B: Conventional coagulation-flocculation unit

Capital cost = 30339,00 KES

Maintenance cost = 1 % of 30339,00 = 3034,00 KES per annum

Operation cost

Amount of alum required = 72 mg/l x 250000 per day

$$= \frac{365 \times 72 \times 250000}{10^6} \text{ kg/a}$$

$$\text{Annual operation cost} = \frac{365 \times 72 \times 250000}{10^6} \times 5,60 = 36792,00 \text{ KES per annum}$$

Present worth

Capital cost = 30339,00 KES

$$\text{Maintenance cost} = 3033,90\left[\frac{1,1^{30} - 1}{0,1(1,1)^{30}}\right] = 28595,00 \text{ KES}$$

$$\text{Operation cost} = 36792,00\left[\frac{1,1^{30} - 1}{0,1(1,1)^{30}}\right] = 346767,00 \text{ KES}$$

Summary of present worth analysis

	A: UGBF KES	B: Conventional KES
Capital cost	4600,00	30339,00
Capital renewal cost	110796,00	
Maintenance cost	867,00	28595,00
Operation cost	40818,00	346767,00
Total	157081,00	405701,00

Note: 1 USD = 16,1 KES