CSIR

DIVISION OF WATER TECHNOLOGY

DEVELOPMENT OF A TWO-STAGE COUNTER-CURRENT POWDERED ACTIVATED CARBON - DISSOLVED AIR FLOTATION SYSTEM FOR THE REMOVAL OF ORGANIC COMPOUNDS FROM WATER

FINAL REPORT

by

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INDEX

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ABSTRACT

The combination of the dissolved air flotation (DAF) and activated carbon adsorption technologies for the treatment of eutrophied water was studied.

The DAF process has proved to be highly suited for the removal of algae in the raw water, while activated carbon is very effective for the removal of taste and odour compounds that sometimes are characteristic of eutrophied waters. The DAF technology is used as a method to remove powdered activated carbon (PAC) from the water along with the algae.

Objectives for the study were :

- To conduct a literature survey on the current status of the relevant technologies in the field of treatment of eutrophied waters and the treatment of unacceptable tastes and odours;
- to compare the efficiency of settling and DAF for PAC removal;
- to optimize PAC removal by DAF in terms of coagulant type, dosage and DAF recirculation rate;
- to investigate the adsorption capacity and rate of adsorption of coagulated PAC;
- to assess on bench scale the adsorption efficiency of various particle sizes of activated carbon;
- to assess the influence of activated carbon particle size distribution on its settling performance;
- to construct a two stage counter-current powdered carbon/dissolved air flotation (PACDAF) mobile pilot plant; and
- to establish locally an analytical method for the qualitative and quantitative determination of two taste and odour producing compounds, geosmin and methyl-isoborneol (MIB).

Results obtained from laboratory tests and PACDAF pilot plant tests indicated that :

- removal of PAC by DAF produced a statistically significant higher removal efficiency than settling;

- PAC can be efficiently removed by DAF from residual turbidity levels of around 4.5 NTU down to around 1 NTU;

- alum and ferric chloride are most efficient as coagulants with dosages of 10 mg/ℓ respectively for the removal of PAC by DAF;
- a recirculation rate above 10 % produces reasonable PAC removal;
- carbon particle size fractions larger than 60 microns are not influenced by coagulation;
- the influence of alum and ferric chloride flocculation on the adsorptive capacity of the activated carbon is slight and is considered insignificant;
- the adsorption capacity of PAC is independent of particle size for the particle size range of 20 - 600 microns studied;
- increasing coagulant concentrations have an adverse effect on the rate of adsorption;
- particle size distribution had a significant effect on the adsorption rate of the model compounds, phenol and DBS, with the adsorption rate at smaller particle sizes much higher than the adsorption rate at larger particle sizes;
- activated carbon particles below 60 microns settle slowly with some of the powdered carbon remaining in suspension for several hours; and
- one DAF unit seem to be sufficient for the treatment of carbon particle suspended water.

A method has been established at the University of Pretoria for the analytical determination and quantification of the odour-producing compounds, geosmin and 2-methyl-isoborneol, commonly associated with high concentrations of certain algal species in eutrophied water sources.

LIST OF TABLES

LIST OF FIGURES

Page

Page

1. INTRODUCTION

Large areas of South Africa receive medium to low summer rainfall. The country has a growing population and water is its most limiting natural resource. Water in fact determines the population capacity of the country. This capacity is estimated at 60 to 80 million people and will be reached by the middle of the next century if the present population growth rate cannot be reduced (1).

Water quality is influenced by such factors as availability, pollutant point sources, and pollutants produced by biological and chemical processes taking place in water bodies. The main water quality problems are eutrophication, mineralization, organic pollution, sedimentation and contamination by pathogens, parasites and hazardous industrial chemicals (2). These problems are aggravated by the increase in population which leads to increased controlled and uncontrolled waste discharges and industrial pollution.

Eutrophication is described as the enrichment of water sources and impoundments as a result of the discharge of plant nutrients (3). This process can be greatly accelerated by man and could lead to hypertrophic conditions under which prolific algal and aquatic plant growth may occur and seriously compromise the quality of such water. Eutrophication in South Africa, in particular in the low-rainfall areas of the Transvaal, is aggravated by the relatively high ambient temperatures, abundance of sunlight, uncontrolled discharge of untreated sewage effluents (2,3), the relatively low seasonal rainfall and high phosphorus levels due to industrial discharges and detergent-use (4). The temperature of water bodies ranges from 2 °C to 32 °C with an annual mean of 19,5 °C, whilst the mean annual precipitation is 700 mm, occurring mostly during the summer months of October to March (5).

The most relevant problems associated with the eutrophication of water sources in South Africa are:

- increased purification costs for producing potable water (2,3);
- deterioration of aesthetic qualities of the impoundment (2,3);
- interference with recreational uses of the water (2,3);

- danger to livestock from ingestion of toxic substances associated with algal blooms (6);
- health effects, such as skin-irritation and diarrhoea associated with cyanobacteria (3);
- creation of anaerobic strata or hypolimnia in lakes, which affect aquatic plant and animal life (2,3);
- financial losses due to increased water treatment costs, decreased recreational use, reduction in value of riparian properties and problems regarding the application of water in industry and agriculture (7);
- formation of organohalogen compounds as a result of water treatment, more specifically chlorination (6); and
- production of unacceptable tastes and odours in potable water treated by conventional means (2,3).

The control of the latter two problems, and particularly the problem of unpalatable or malodorous water, constituted the focus of this study.

Objectives for the study were :

- A literature survey on the current status of the relevant technologies in the field of eutrophied waters and the treatment of unacceptable tastes and odours;
- to compare the efficiency of settling and dissolved air flotation (DAF) for powdered activated carbon (PAC) removal;
- to optimize PAC removal by DAF in terms of coagulant type, dosage and DAF recirculation rate;
- to investigate the adsorption capacity and rate of adsorption of coagulated PAC;
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- to establish locally an analytical method for the qualitative and quantitative determination of two taste and odour producing compounds, geosmin and methyl-isoborneol (MIB).

2. THE PRODUCTION OF POTABLE WATER FROM AN EUTROPHIED SOURCE

2.1 Defining the problem

The most obvious and most favourable long-term solution to the problem of producing an aesthetically acceptable and odour-free water from an eutrophic source, is to introduce measures which will minimize or prevent the formation of unwanted contaminants. The following four alternatives have been proposed for the control of eutrophication in the USA (8):

- limiting the nutrient contact of the water;
- managing the aquatic system to create a food chain which will provide valuable and harvestable crops;
- stimulating natural enemies, such as diseases and parasites of organisms and plant life which give rise to unwanted organic material; and
- using toxic control measures, such as herbicides and algicides.

In support of the first measure, a special standard of 1 mg/ℓ phosphorus (as PO_4^--P) was introduced in 1985 in sensitive catchment areas in South Africa (2). Treatment of the water source itself, specifically for the removal of tastes and odours, has been applied in various reservoirs and has met with varying success. These methods include aeration of the water body and application of oxidants (such as chlorine) or algicides (such as copper sulphate). In South Africa the impoundments showing serious problems due to eutrophication are normally large and relatively shallow, and have dimensions which prohibit the application of these methods on large scale at reasonable costs. The treatment of small reservoirs which supply rural communities may be feasible, but the cost of applying such methods is mostly prohibitive.

It appears therefore that the production of potable water from eutrophied sources is a water treatment problem. This problem is typically of a dual nature, in that both dissolved odourous organic compounds, plant matter and microorganisms like cyanobacteria and algae that produce these compounds, need to be removed. If chlorination is practised, the concomitant problem of organohalogen compounds (typically trihalomethanes) and their precursors presents a similar difficulty.

Cyanobacteria and algae in eutrophied waters are known to produce organohalogen precursors, either as dissolved extracellular products or as fragments of decaying organisms (9). In this case too, both the microorganisms and the dissolved products they produce, must be removed in order to solve the whole problem.

2.2 Removal of algae

The algae and cyanobacteria found in the surface areas of lakes require sunlight for photosynthetic growth and many of the species found in South African lakes have buoyancy mechanisms. Thus colonies of the cyanobacterium *Microcystis aeruginosa* tend to float below the water surface due to their gasfilled vacuoles (10). For this reason it is difficult to separate flocculated algae from a eutrophic water source by sedimentation. Prechlorination of the raw water may improve sedimentation, but this has the disadvantage of greatly increasing the organohalogens in the water, which in turn requires specific treatment (9). Conventional coagulation/sedimentation methods have generally not been effective in removing the odours produced by micro-organisms. In fact, prechlorination resulted in additional odours of medicinal nature in the water from the Hartbeespoort Dam. The effect of poor clarification is alga carryover to the final sand filters resulting in poor filter performance, short filtration cycles between backwashing, penetration of algae to the distribution system and concomitant odour problems (11).

Investigation of this problem at the Hartbeespoort Dam by the CSIR's former National Institute for Water Research, now the Division for Water Technology (WATERTEK), led to the conversion of the three existing settling tanks at the Schoemansville water treatment works to one flocculation tank and two dissolved air flotation (DAF) tanks. A schematic representation of the DAF unit at the Schoemansville treatment plant is shown in Figure 2-1.

Briefly, the DAF process comprises the chemical coagulation and flocculation of the raw water in the flocculation tank after which it is introduced into the reactor zone of the flotation tank where it is mixed with a recycled stream of clarified water containing dissolved air (11). The recycled stream, at a pressure of 400 kPa, is injected through a specially designed nozzle from which the dissolved air is released in the form of

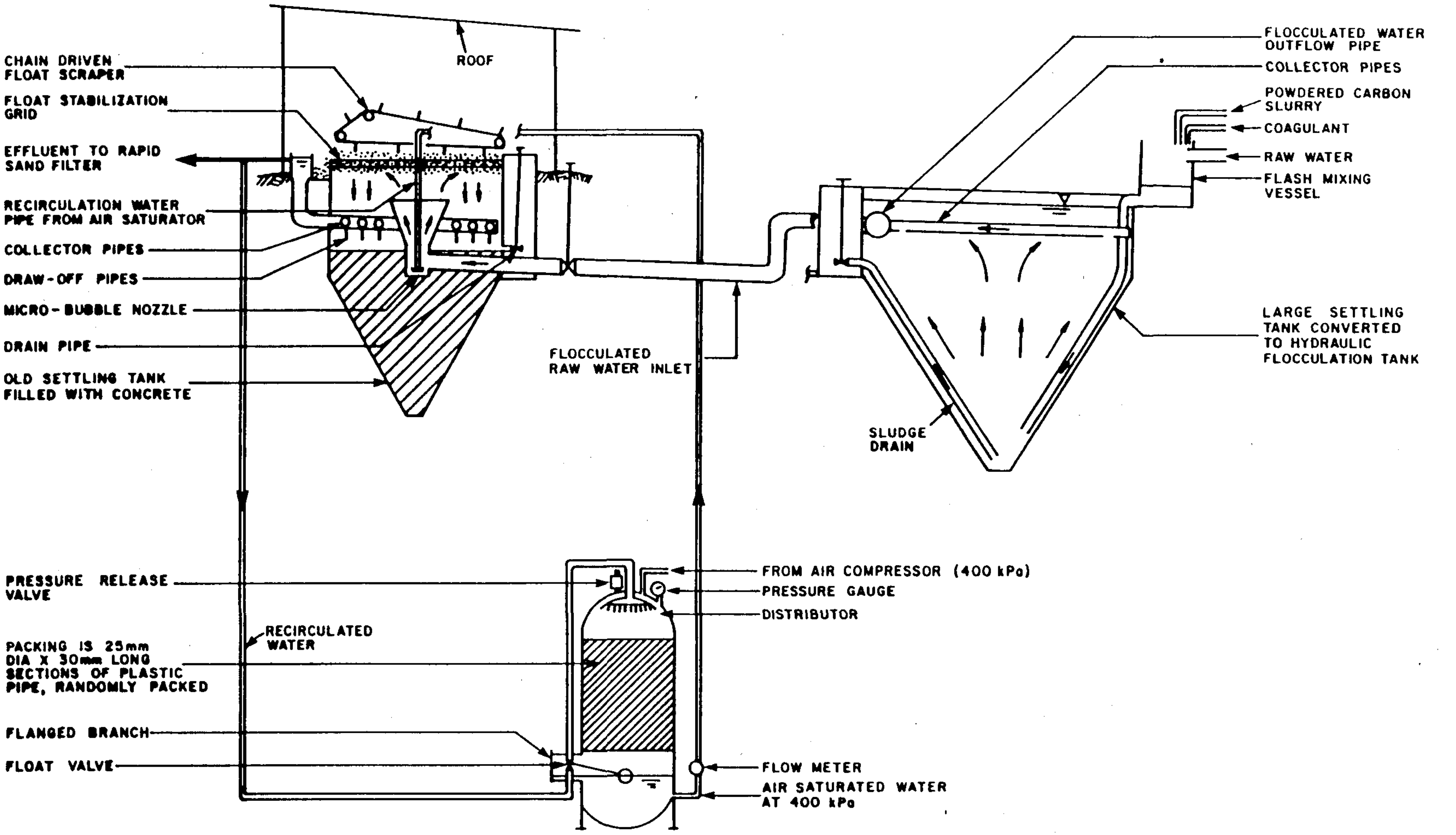


FIGURE 2-1
SCHOEMANSVILLE DISSOLVED AIR FLOTATION PLANT UTILIZING POWDERED ACTIVATED CARBON

microscopic bubbles. The bubbles adhere to, or become enmeshed in, the flocculated biomass causing the flocs to rise to the surface. Aided by their natural buoyancy, the flocculated mass forms a sludge blanket on the water surface in the reactor. The sludge is removed by hand or by mechanical scraper (11). More details on the theory of dissolved air flotation and its application at other local eutrophied water sources are presented by Bratby and Marais (12) and Van Vuuren and co-workers (13).

The DAF units described above, followed by rapid sand filters, were successful in clarifying the algae-laden water withdrawn from the Hartbeespoort Dam (11). The turbidity of the raw water ranged between 5 and 30 NTU and was reduced effectively to below 2 NTU throughout the year. However, though the algae had been removed, the water still had an unacceptable odour. In addition, the sludge from the DAF units had to be disposed of quickly, since the warm ambient temperatures during most months of the year led to rapid decomposition and associated odour problems of a different nature (14).

The DAF process alone, or preceded by sedimentation, has proved to be the solution to the algae-related clarification problem associated with eutrophic waters (11). The other facet of the problem, namely taste and odour removal, is however not solved by coagulation separation processes and alternative means are required.

2.3 Removal of odours associated with eutrophic waters

If tastes and odours in a water source can not be prevented by treatment of the source itself, then removal of the odours is indicated. Removal methods can be subdivided into methods of destruction and methods of removal of the odorous compounds (8). Oxidative destruction of odours by chlorination has the disadvantage of producing chlorinated organics, which may include potentially carcinogenic organohalogens (9) or chlorinated phenolic compounds which have an objectionable medicinal odour (15). The CSIR, has in fact measured relatively high levels of organohalogen precursors (460 to 670 $\mu g/\ell$ Total organohalogen precursors (TOHp)) in raw water from the Hartbeespoort Dam. Both chlorine dioxide and ozone treatment involve on site generation of the oxidant with high capital costs and relatively specialized operator and maintenance requirements. These oxidants have also been found to introduce odours of their own into the water: in the case of ozone fruity odours and in the case of chlorine dioxide fishy and kerosene-like odours have been reported, where an excess of the oxidant was employed (15).

Activated Carbon Treatment

As an alternative to oxidative destruction of odour compounds, their removal by adsorption onto activated carbon has proved to be an effective treatment process (15).

Activated carbon is commercially available in powdered or granular form. Powdered activated carbon (PAC) is generally used in batch or continuously stirred reactors and granular activated carbon (GAC) in packed or fluidized bed reactors (16). In selecting the appropriate form of activated carbon for a particular application, studies on carbon dosage reactor efficiency, pretreatment and post-treatment envisaged, filter backwash costs, losses of GAC due to attrition during handling, cost of PAC versus GAC, available regeneration facilities and expected fluctuation in raw water quality, should be conducted (17). Thus a packed GAC column which operates in plug-flow mode will theoretically have a higher removal efficiency, and it requires a large initial capital investment and periodic backwashing to contain bacterial growth. GAC columns are usually operated in conjunction with a regeneration system (17).

PAC on the other hand, is used in theoretically less efficient stirred tank reactors , but has the following advantages for the situations outlined above (17):

- PAC reaches adsorption equilibrium more rapidly than GAC;
- PAC can be used in an existing water treatment facility without major adaptations or additional capital investment;
- PAC can be applied intermittently and at varying dosages in accordance with fluctuating treatment requirements; and
- PAC has a lower cost per unit mass than GAC, particularly when they are compared on a once-through basis.

The use of PAC therefore appears to hold considerable promise for the removal of tastes and odours at small drinking water treatment facilities, in particular where the quality of the water is subject to seasonal variation. This is in fact the case in most of the summer rainfall areas of South Africa. In these areas water quality during the winter is relatively good and subject to little variation, but the thunderstorms in spring cause rapid and drastic deterioration of the water quality by washing animal wastes and detritus, as well as fertilizers, into the reservoirs which gives rise to the proliferation of algae in the form of blooms. Consistent summer rainfall has a dilution effect which leads to an improvement in water quality. In areas or periods when summer rainfall remains intermittent and low, no dilution effect takes place, and the water quality remains poor. The widespread use of PAC to control odours elsewhere is confirmed by a survey indicating that 54 surface supplies in the USA and Canada used PAC at dosages of 0,25 to 60 mg/ℓ (media 5 mg/ℓ) for taste and odour removal (8).

Several laboratory and pilot scale investigations have been carried out to determine the efficiency of PAC for the removal of taste and odour producing compounds such as geosmin and methylisoborneol (MIB) (15,18). Thus significant geosmin and MIB removal has been found with PAC dosages of 10 to 25 mg/ℓ PAC and in another study 50 mg/ℓ PAC was found to achieve high removal rates for several odorous compounds (15). Lalezary *et al* (18) found in pilot plant PAC systems that PAC dosages of 10 mg/ℓ can successfully bring geosmin and MIB levels of up to 66 ng/ℓ down to acceptable levels, (less than 10 and 29 ng/ℓ for geosmin and MIB respectively) and for the more common levels of approximately 20 ng/ℓ only half this concentration of PAC was sufficient. On the other hand, the efficiency of removal was drastically impaired by the presence of chlorine and chloramine residuals, and background organics, notably humic acids (18).

It is important to note that the type of activated carbon employed for odour removal should be carefully selected to ensure optimal results. On economical grounds, it has been suggested that PAC is economical to use at continuous dosages below 25 mg/ℓ, and at higher dosages GAC becomes a feasible alternative (14).

A major difficulty in using PAC, however, is its separation from the water after adsorption has taken place. PAC is a very fine powder with a typical particle size distribution of 75-80% between 10 and 50 micron particle diameter (19).

Separation is usually effected by sand filtration, which may be preceded by coagulation and/or sedimentation. High dosages of PAC entail the risk of powder penetrating the filters and entering the distribution system (8). It has been reported that 25 mg/ℓ is the maximum dose of PAC which can be applied without limiting filter runs excessively (20).

2.4 The PACDAF process

The dissolved air flotation process shown in Figure 2-1 has proved to be highly suited for the removal of PAC, together with the algae in the raw water (11). The Schoemansville water treatment works applied 10 mg/ℓ of PAC which was introduced into the flocculation tank, together with ferric chloride and a polyelectrolyte as a coagulation aid. Any PAC which penetrates the DAF process is removed subsequently by the rapid sand filters.

A further advantage of the introduction of the combined PACDAF process at Schoemansville was that after PAC addition the sludge from the DAF units became more dense, less slimey and altogether easier to handle manually (11). The sludge, once dumped on site and awaiting removal by truck, no longer presents an odour problem as a result of decay. Presumably the PAC has a residual capacity for the removal of odours emanating from the waste algae. The effect of PAC as a conditioning agent in activated sludge processes has been reported (21,22) and it is believed that similar considerations apply.

Optimizing the DAF Process with PAC

The combination of PAC with the DAF process has been shown to be effective for the removal of both algae and the associated odours from water drawn from a hypertrophic source. In order that the full potential of this system be realized however, the PAC must be applied only when the water quality warrants odour removal. Thus variation of the PAC dosage in accordance with the intensity of the odour in the raw water can bring about substantial savings in running costs. No quantitative studies to this end have been conducted at the Hartbeespoort Dam, but indications are that PAC addition may be required only for 3 to 6 months of the year and in most cases at dosages ranging from 2 to 10 mg/ℓ. PAC is by far the most expensive running cost item on the plant and its use can be optimised as follows:

- by applying only the optimum dose required for complete odour removal at any given time; and
- by optimising the PAC contact system in order to make more efficient use of the PAC and thereby lower the dosage rate.

The latter option forms the subject of this project.

Optimising the PACDAF Reactor Configuration

Generally speaking the PACDAF configuration has not been established as a unit treatment process in conventional water treatment. Letterman and co-workers (23) studied the removal of PAC from water by means of alum coagulation and precipitation. More specifically, they investigated the coagulation of PAC suspensions ranging from 25 to 500 mg/ℓ at pH 7 and an alkalinity of 2 meq/ℓ, and found effective coagulation at alum doses ranging from about 10 to 100 mg/ℓ. They found significant PAC coagulation taking place without the addition of a coagulant. These findings suggest that PAC should be added to the raw water prior to the coagulant, in a separate contact reactor.

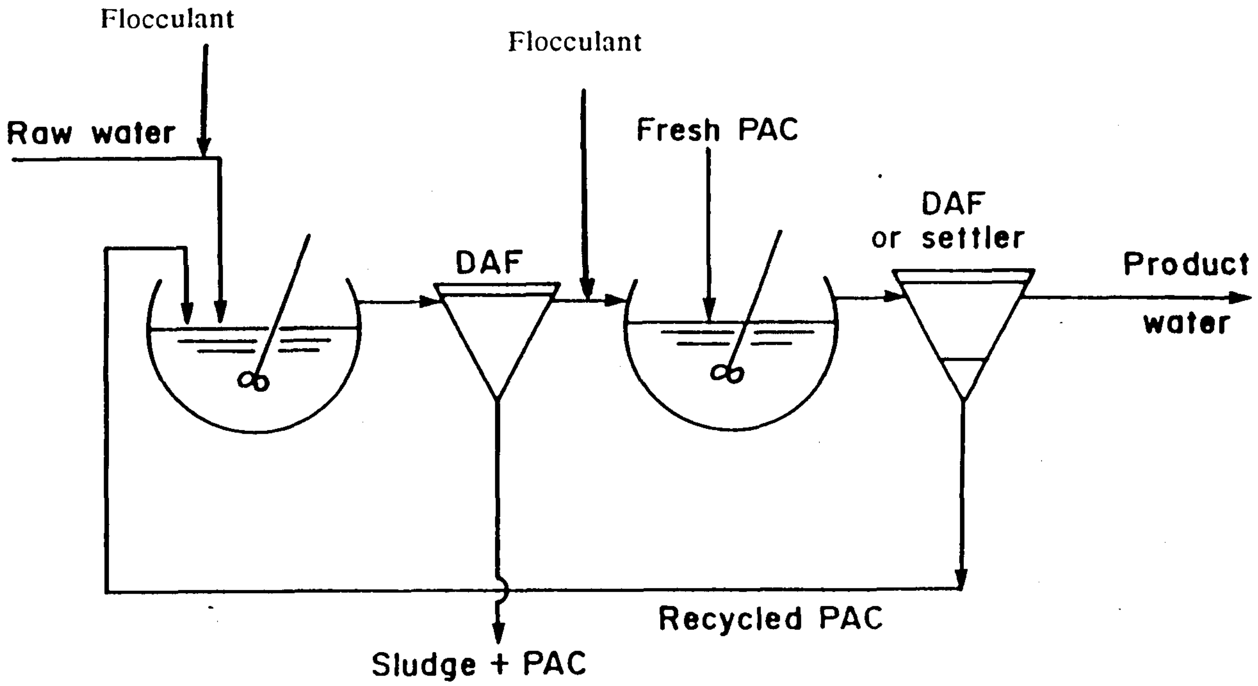
Letterman *et al* also found that the pH and alkalinity of the water have an effect on PAC removal, with optimum pH values of 6,8 and 7,4 being associated with alkalinities of 4,0 and 0,6 meq/ℓ, respectively.

Lettinga and co-workers (24) addressed the question of the fouling of PAC during flocculation. They considered anionic, cationic and non- ionic polyelectrolytes at relatively high PAC concentrations (mostly 500 mg/ℓ) and found the rate of adsorption onto flocculated PAC to be somewhat lower than onto non-flocculated PAC. The adsorbates employed in the study were phenol, cresol, nitrobenzene, 2-nitrophenol and 2,4-dichloro-phenoxy-acetic acid. The cationic polyelectrolyte generally exhibited a smaller fouling effect on the PAC, though the brand of polyelectrolyte had an influence on the adsorption rate. Stander and co-workers (25) investigated the coagulation, settleability and adsorption behaviour of PAC when coagulated with aluminium sulphate (alum), with and without polyelectrolyte as a coagulant aid. Whereas aluminium sulphate brought about good PAC coagulation, the addition of a polyelectrolyte coagulation aid displayed excellent coagulation properties and high settling rates. This combination caused a reduction in adsorption performance of the PAC, and for COD removal it was found necessary to allow a precoagulation contact time of 15 minutes.

Further optimization of the PACDAF process can theoretically be effected by employing a two-stage counter-current reactor system as shown in Figure 2-2. Thus increasingly loaded PAC will be transferred from reactor to reactor counter-current to the flow of water through the system. In practice a two-stage counter-current system may constitute the maximum number of stages which can be economically justified. Wallace and Burns (26) reported the evaluation of a pilot plant system in which the PAC was contacted with the wastewater in two clarifier-settlers after chemical pretreatment of the raw water with alum and ferric chloride. They found increased soluble COD removal in the two stage counter-current system compared to a single stage system. On an economical basis, the former system was recommended only for the treatment of relatively strong wastewaters (26).

It has therefore been established that the two-stage counter-current system should operate more efficiently for the removal of odorous compounds from water. Whether such a system is justified for the removal of odorous organics only, is best established by a small bench-scale continuous flow unit. Indications are that coagulation pre-treatment significantly enhances organics removal (26) and that the PAC and wastewater should be mixed in a pre-contact tank prior to the addition of coagulants (24,25).

In the suggested system for the treatment of algae-laden raw water as shown schematically in Figure 2-2, fresh PAC is added to the second contact reactor to polish the partially treated effluent from the first reactor. Relatively pure PAC from the second reactor with a residual adsorption capacity, is then separated by DAF, and recycled to the first contacting reactor where it is brought into contact with the algae-laden raw water. The algae and exhausted PAC are finally removed by DAF after the first reactor.



DAF - Dissolved air flotation
PAC - Powdered activated carbon

FIGURE 2-2
PROPOSED TWO-REACTOR COUNTER-CURRENT PACDAF SYSTEM
Schematic flow diagram

In practice, where there is a seasonal variation in water quality and algae-content of the raw water, provision may be made to operate the system on one reactor only (with fresh PAC being added to the first reactor) if the quality of the raw water improves significantly. The single reactor configuration would still be used even when no PAC is required.

3. OBJECTIVES

The foregoing two sections outlined the reasons for undertaking the project and the current status of the relevant technologies in the field. The first specific objective of the project was an ongoing literature survey, and information from the literature was integrated into these sections.

As indicated, the application of activated carbon in a fine or powdered form is subject to the problem of efficient removal thereof. Following application in stirred tank reactors, fine activated carbon particles are in practice either filtered directly or coagulated and settled, usually followed by filtration (8,23). In the gold recovery process, granular carbon is removed from the pulp by screens (27). Any system using fine activated carbon must incorporate an efficient removal mechanism, and this aspect constituted one of the thrusts of this project. One of the stated objectives was to compare the efficiency of settling and dissolved air flotation for powdered activated carbon (PAC) removal. Another objective was an assessment of the influence of activated carbon particle size distribution on its settling performance. The latter objective was combined with an assessment on bench scale of the adsorption efficiency of various particle sizes of activated carbon, so as to determine an optimum particle size range in which both adequate settling and rate of adsorption are combined. If such an activated carbon can be provided, a simple contact and separation system will be possible in which the carbon can readily be recycled between successive reactors.

Research to date by Letterman *et al* (23), Lettinga *et al* (24), Stander *et al* (25) and Wallace and Burns (26) on the coagulation (flocculation) and removal of PAC by settling was discussed in Section 2.4 under the sub-heading dealing with optimization of the PACDAF process. None of this work relates to removal of PAC by DAF and the perceived importance of these aspects underlie three specific objectives of this project, viz the optimization of PAC removal by DAF in terms of the coagulant type and dosage, and the DAF recirculation rate. These related objectives will be considered in one section (See 4.1.4).

Due to the complexity of the adsorption process, which involves several diffusion mechanisms besides true adsorption, the order of the adsorption rate equation probably changes with time. If it is assumed that the reaction rate could lie between first and second order, then the theory of reaction kinetics establishes that for identical feed composition and flow rate, the volume (or space time) of a continuously stirred tank reactor (CSTR) will always be larger than that of a plug flow (fixed bed) reactor (28). To illustrate this principle at 90% removal (conversion) in simple hypothetical reaction orders of 0,5; 1,0 and 2,0, the volume of a CSTR will theoretically be twice, 4 and 10 times larger than the corresponding plug flow reactor. The more mixed reactors combined in series, the better will be the approximation of plug flow conditions, so that for a first order reaction, two equally sized CSTR's will have a combined volume requirement of less than 50% lower than that for a single CSTR (28). This theoretical illustration provides ample motivation for the investigation of a two-reactor PAC system in which activated carbon is transferred between the reactors counter-current to the flow of water as shown in Figure 2-2.

For such a system to be viable, the PAC must be separated from the feed water at least once and be reintroduced into an earlier reactor. If separation is effected by settling or flotation of coagulated PAC, adsorption efficiency in this state should not be greatly impaired. These considerations prompted the formulation of the final objective for laboratory research in terms of which the adsorption capacity and rate of coagulated PAC was to be investigated. For this study two model organic compounds with different adsorption characteristics were employed, viz phenol and dodecylbenzene sulphonate (DBS). These compounds are readily and inexpensively analysed by means of ultra-violet spectrophotometry, whereas odorous compounds (eg geosmin and MIB) and halogenated compounds (eg THM's) require expensive and time-consuming analysis.

The question of quantitative analytical determination of odour compounds, served as motivation for another specific objective. This objective involves the establishment locally of an analytical method for the qualitative and quantitative determination of geosmin and MIB concentrations. This method was to be evaluated by analysing a number of local water sources to quantify their geosmin and MIB contents, if indeed these were measurable. The establishment of the Grob extraction method for these two compounds followed by gas chromatography (GC) and mass spectrometry (MS) analysis of the concentrate was undertaken by the Institute for Chromatography of the University of Pretoria and their report is enclosed as Appendix 1.

The operation manual of the two-reactor PACDAF pilot plant system is enclosed in Appendix 3.

4. PACDAF LABORATORY STUDIES

4.1 Removal of powdered activated carbon by dissolved air flotation

4.1.1 Experimental procedure

All batch laboratory experiments were conducted on a bench scale dissolved air flotation (DAF) unit comprising six 1,5 liter cylindrical perspex containers with conical bottoms. Each container was fitted with a variable speed stirrer, a dissolved air release nozzle and several drainage and draw-off points. Air was dissolved in a packed air saturator at 400 kPa by continuous circulation of tap water from a compressor. The settling experiments were conducted in the same containers. Turbidity was measured by means of a Hach (Model 2100 A) turbidimeter.

All DAF experiments employed a standard water application powdered carbon, SA45, supplied by NORIT SA and distributed locally by Holpro Chemicals (Pty) Ltd. Analytical grade aluminium sulphate (alum), ferric chloride and polyaluminium chloride were employed, and the cationic, anionic and nonionic polyelectrolyte flocculation aids were supplied by Allied Chemicals (brand names being Zetag 57, Magnafloc 156 and Percol 351 respectively).

Distilled-deionized water, free of organic and inorganic contaminants was buffered by addition of 0,002 M sodium bicarbonate (NaHC03) which resulted in a pH of about 8. Each container received 1 000 mℓ of this water and the desired amount of PAC was then added and thoroughly mixed to form a suspension. Flocculation involved 3 minutes of rapid mixing of 100 rpm and 20 minutes of slow mixing at 40 rpm. Following coagulation in the containers, a volume of water saturated with air at 400 kPa was injected into each container via the release valve, thus liberating finely dispersed micro-airbubbles which attach to the flocs and carry them to the surface. Turbidities were measured before and after each experiment and one control (without coagulant) was maintained per batch of experiments. The percentage of DAF recirculation rate was determined by the percentage of air-saturated water introduced into each reactor.

4.1.2 Preliminary investigations

Measurement of Suspended PAC Concentration

Three methods were investigated over a range of 0 to 59 mg/ℓ PAC:

(i) Turbidity (Hach model 2100A Nephelometric turbidimeter);
(ii) Absorption of light at a visible wavelength using a Carl Zeiss M4 QIII spectrophotometer and a 5 cm cuvette; and
(iii) Total suspended solids determination according to the method in Standard Methods, 1985 (16th Edition) (25).

The first method produced a non-linear calibration curve between PAC concentration and turbidity (NTU). This is explained by the fact that nephelometric turbidity measurement involves the determination of light scattered by suspended matter and PAC, which has an intense black colour, tends, at higher concentrations, to absorb rather than scatter light. This prompted the investigation of a light absorbance method ((ii) above), but the extreme experimental scatter rendered this method impracticable. Likewise, the third method produced erratic results and was moreover extremely time-consuming and cumbersome for the large number of evaluations required.

The removal of PAC was therefore determined by measuring nephelometric turbidity and the calibration data was modelled by an appropriate regression model.

Although a power curve of the form

$$(PAC) = 0{,}592\ T\ (-0{,}85) \quad \text{(with } T = \text{turbidity in NTU)}$$

was fitted to the full range of data, it was considered to be more accurate to operate at turbidities below about 1,2 NTU and in this region the following linear correspondence was found:

$$(PAC) = 0{,}069\ T + 0{,}806$$

This method was employed throughout, and turbidity was always cited in terms of NTU's.

Selection of polyelectrolyte flocculation aids

It has been established that activated carbon bears a negative surface charge (as measured by electrophoretic mobility) at pH-conditions upwards of about 5 (29). In the experimental pH-range of around 8, this indicated that oppositely charged (cationic) polyelectrolytes should yield better flocculation and hence removal results for PAC, than their non-ionic and anionic counterparts. This notion was confirmed in preliminary DAF experiments, and all subsequent experiments involving polyelectrolytic flocculation aids were conducted with the cationic species (Zetag 57, from Allied Colloids).

4.1.3 Comparison of DAF and settling for PAC removal

A two-level factorial experiment was conducted to determine the removal efficiency of DAF compared to settling, in the presence of two other factors, viz PAC concentration and coagulant (FeCl3) dosage. Following statistical procedures for this kind of experiment (30), the experiment was conducted in two identical blocks for the following three factors each at a high-(+) and a low(-) level:

a - PAC concentration : (+) = 100 mg/ℓ & (-) = 20 mg/ℓ
b - Removal method : (+) = settling & (-) = DAF
c - $FeC1_3$ concentration : (+) = 50 mg/ℓ & (-) = 10 mg/ℓ

Since only six individual runs could be performed simultaneously, the order of all of the runs was randomized. The design of the experiment is presented in Table 4-1 and the results are summarized in Figure 4-2.

Figure 4-2 indicates that factor *a* had a significant positive effect and *b* a significant negative effect on turbidity. No significant interactions were found between the factors.

Thus DAF produced a statistically significant higher removal efficiency than settling. The statistical significance of the PAC concentration is to be expected and it was somewhat surprising that coagulant concentration appears not to influence PAC removal significantly.

4.1.4 Factors influencing removal of PAC by DAF

Coagulant type and dosage

The results of the bench scale DAF experiments for the removal of PAC are shown in Figures 4-3 to 4-8, each of which represents 35 DAF batch reactor runs. Preliminary screening had established that cationic polyelectrolyte was superior to the anionic and non-ionic species, and that polyaluminium chloride yielded results slightly inferior to those of alum and ferric chloride. The data of Figures 4-3 and 4-5 (in two- dimensional form) was represented in three-dimensional form in Figures 4-6, 4-7 and 4-8 to facilitate interpretation. It is clear that alum and ferric chloride are both suitable for coagulation and removal of PAC by DAF, whereas Figures 4-5 and 4-8 confirm that a cationic polyelectrolyte is substantially less efficient for this purpose. It is readily apparent from the data which concentrations of the coagulants are required to reduce the turbidity to around 1 NTU. It appears that some turbidity always remains, which in practice indicates the use of final filtration after a PACDAF process.

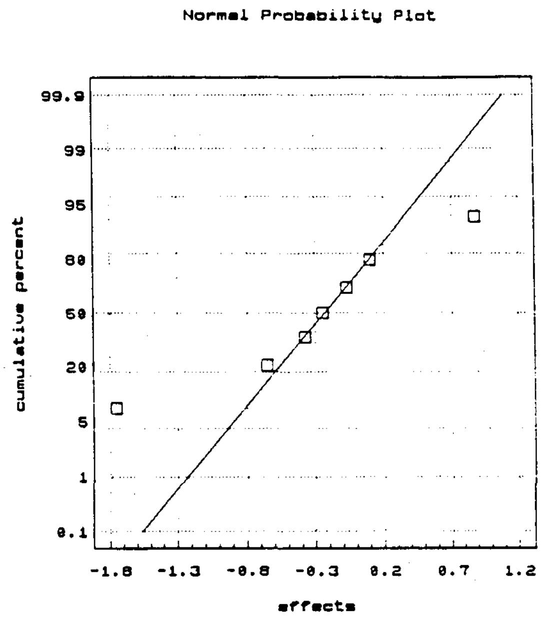
Recirculation rate

The results of different recirculation rates are reflected in Figures 4-9 and 4-10. Whereas a recirculation rate of 5% is clearly too low, it appears that rates above 10% produce reasonable PAC removal at ferric chloride dosages in excess of 20 mg/ℓ. It should be borne in mind that the results of these bench scale tests provide indicators

```
Blocks: 2              Factors: 3            Runs: 16

run        block    response        a b c
(  4)        1      1.1             - - -
( 12)        2      3               + - -
(  3)        2      0.5             - + -
(  1)        1      1.2             + + -
(  6)        2      1.6             - - +
( 13)        1      2.6             + - +
(  8)        1      0.7             - + +
( 16)        2      0.4             + + +
( 11)        1      1.5             - - -
( 15)        2      3               + - -
(  5)        2      0.5             - + -
(  9)        1      0.9             + + -
( 14)        2      2.3             - - +
( 10)        1      4               + - +
(  7)        1      0.4             - + +
(  2)        2      0.5             + + +
```

Table 4-1
Factorial experimental design for comparison of DAF and settling



```
Estimates of factor effects
---------------------------
ave=  1.5125
A  =  0.875
B  = -1.75
AB = -0.65
C  =  0.1
AC = -0.25
BC = -0.375
ABC= -0.075
Blocks: ABC
---------------------------
```

FIGURE 4-2
Results of factorial experiment to compare DAF and settling

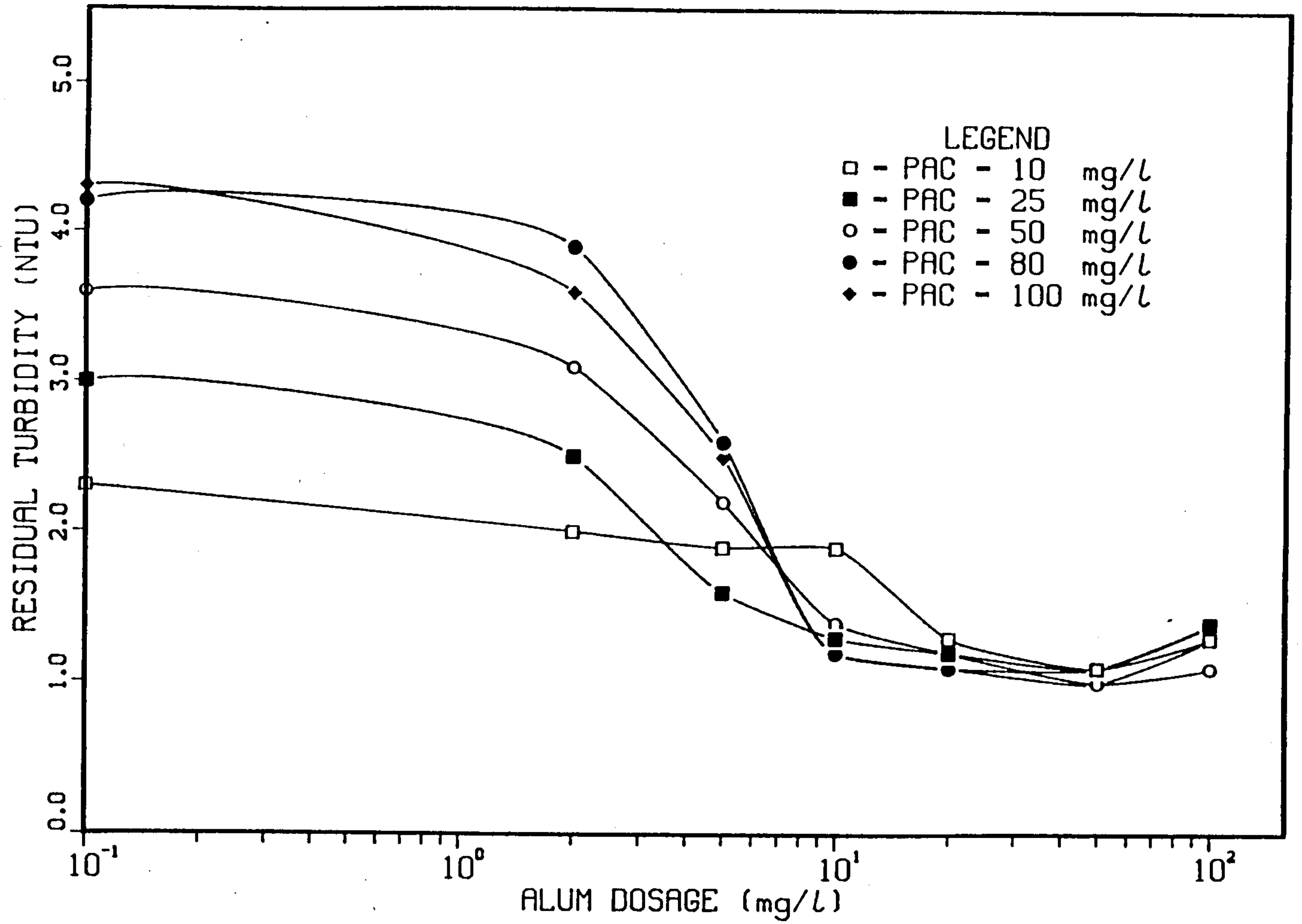


FIGURE 4-3
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of aluminium sulphate (alum) coagulant

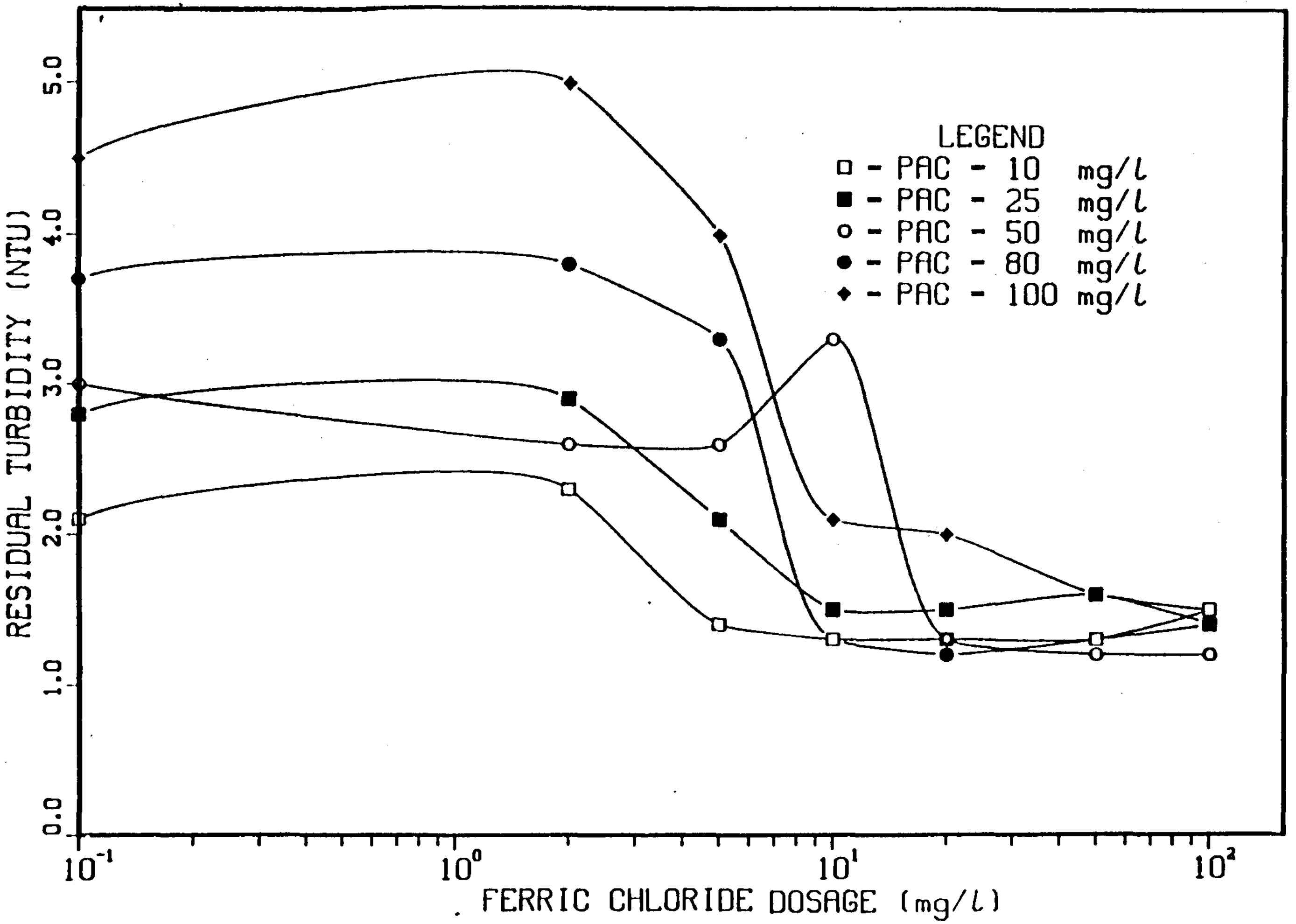


FIGURE 4-4
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of ferric chloride coagulant

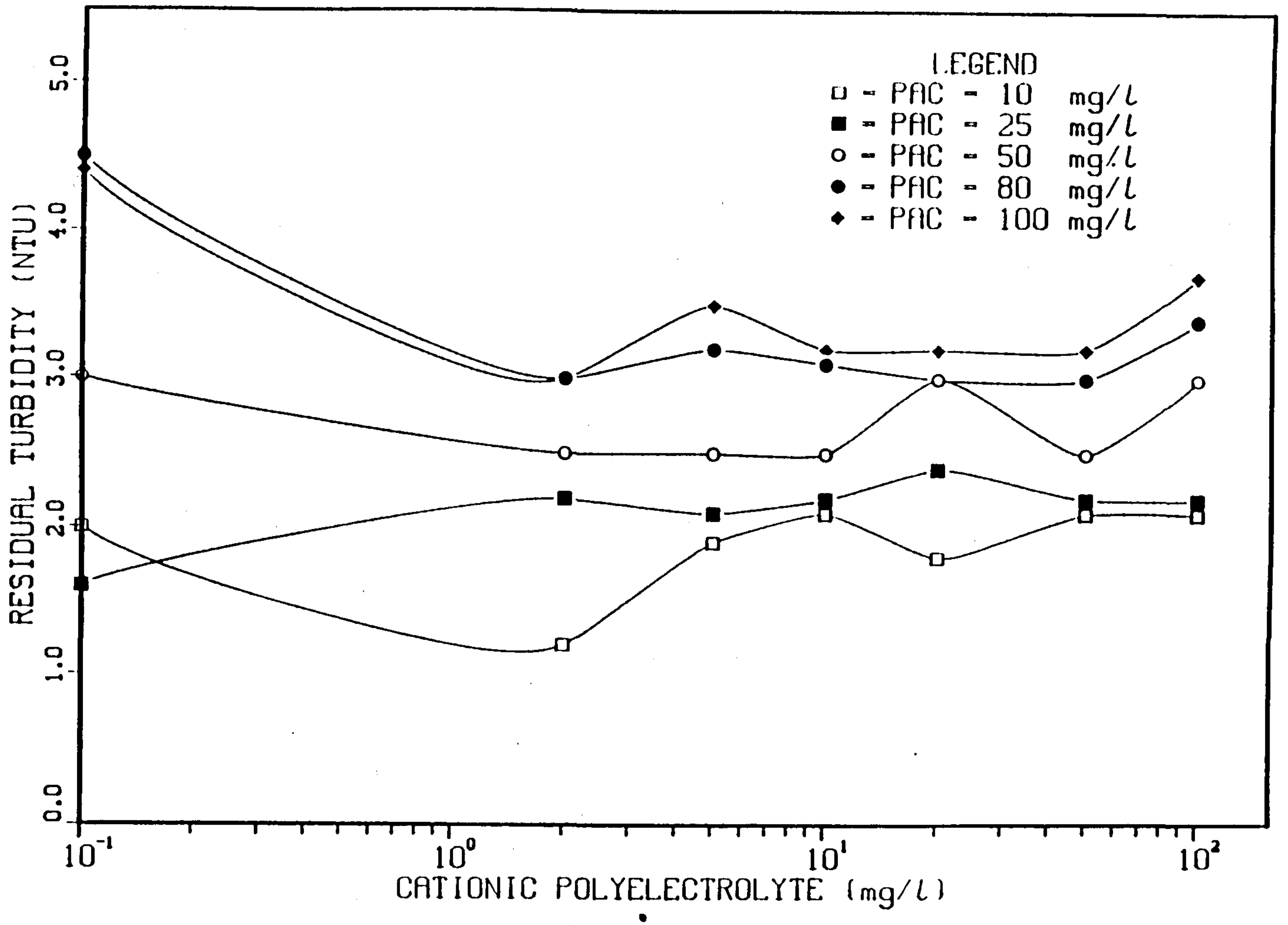


FIGURE 4-5
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of cationic polyelectrolyte coagulant

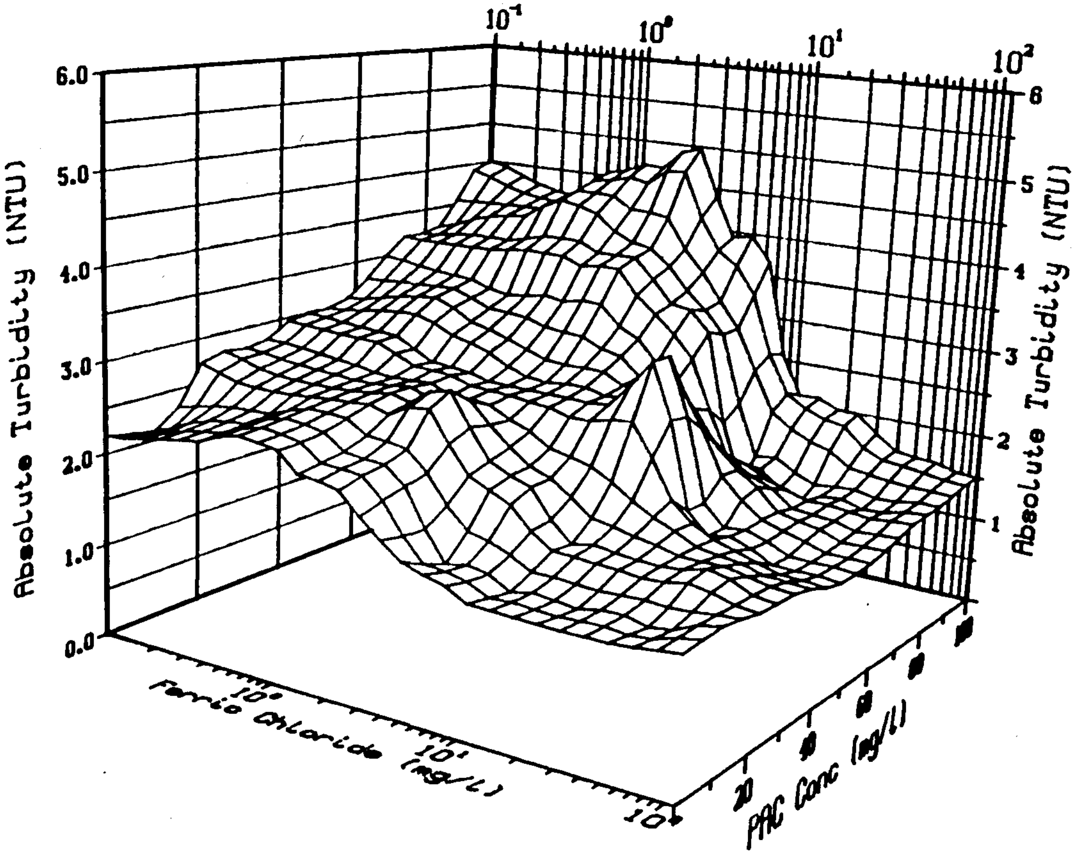


FIGURE 4-6
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of ferric chloride coagulant

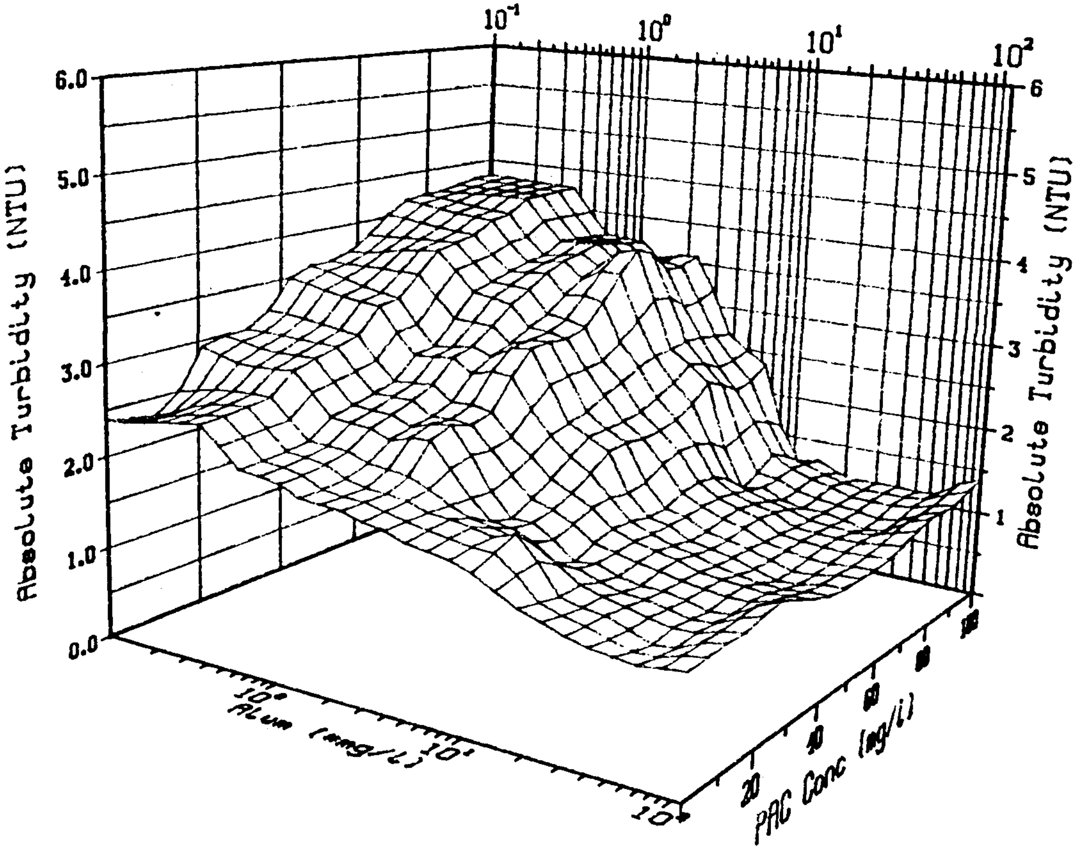


FIGURE 4-7
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of aluminium sulphate (alum) coagulant

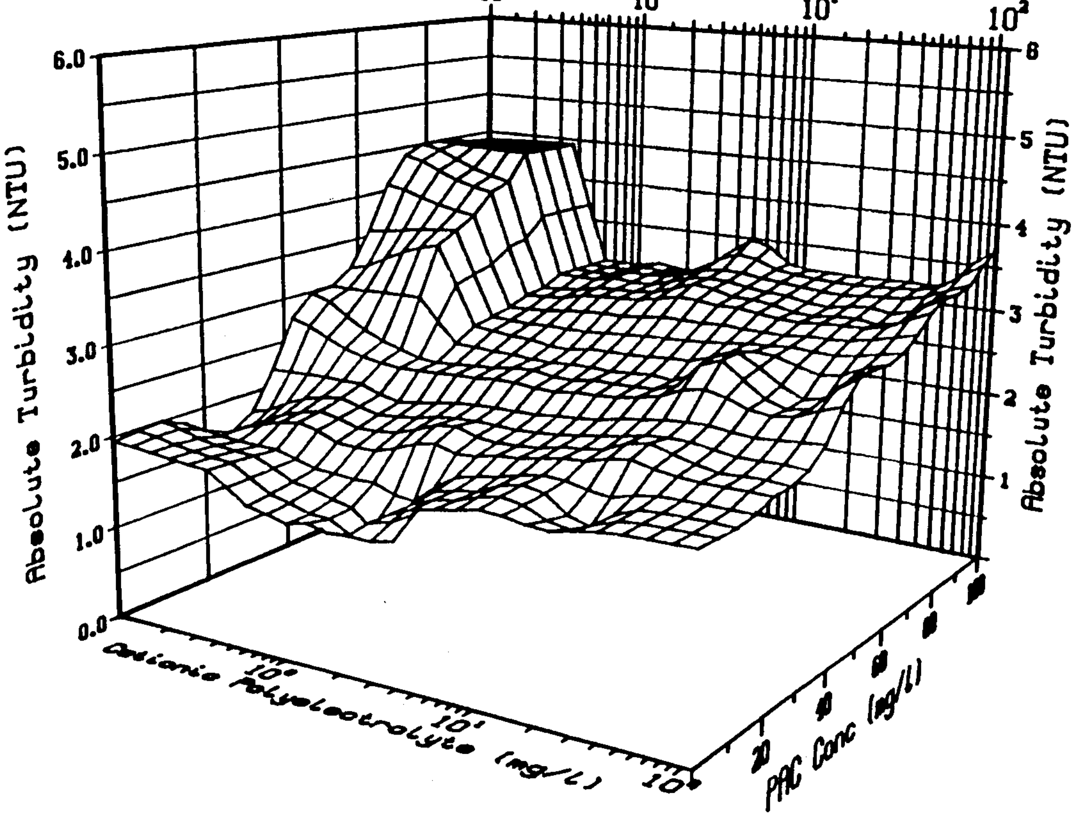


FIGURE 4-8
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Effect of cationic polyelectrolyte coagulant

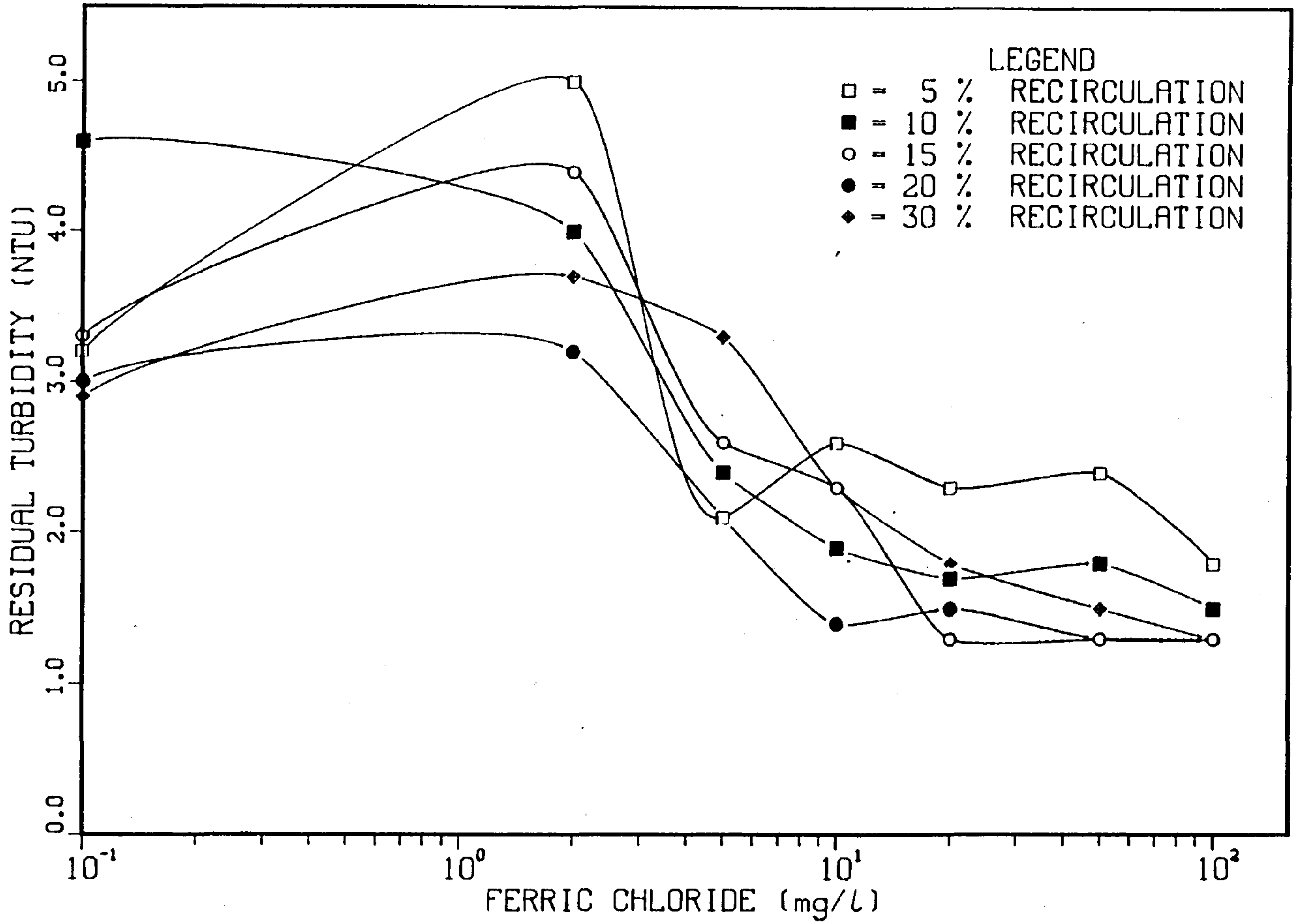


FIGURE 4-9
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Influence of DAF recirculation rate

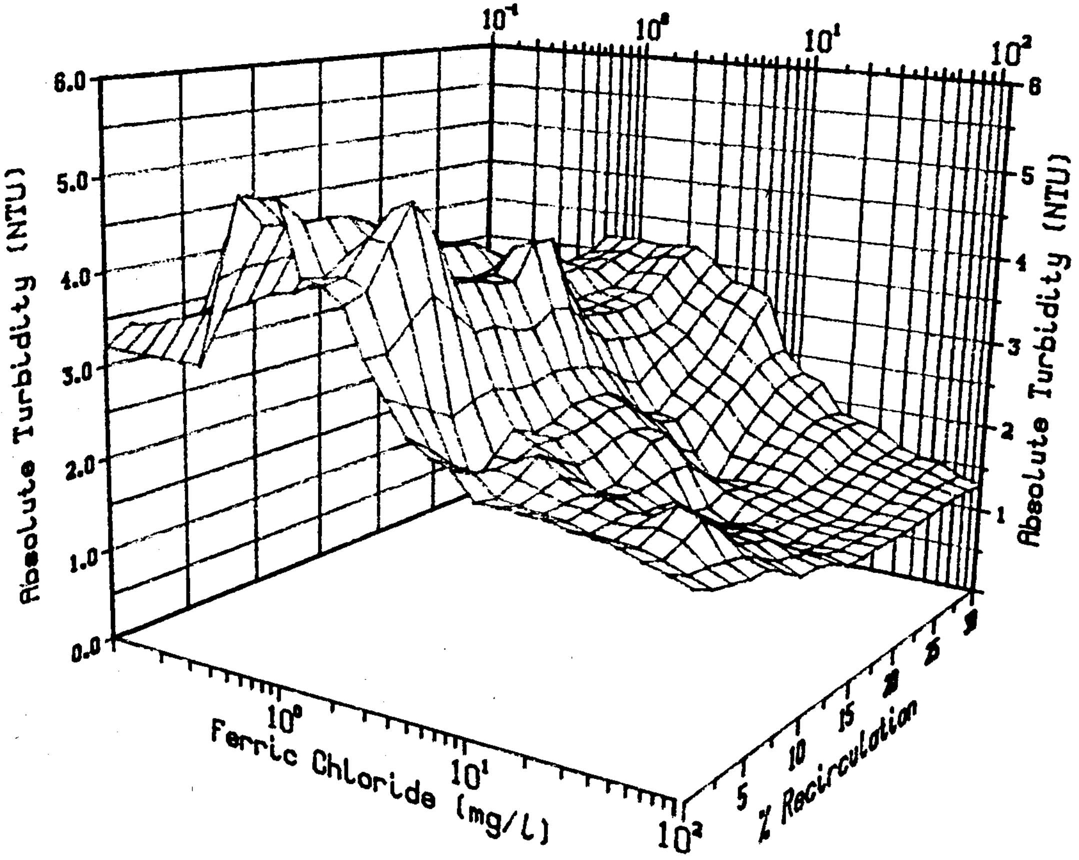


FIGURE 4-10
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Influence of DAF recirculation rate

of a general trend at best and correlation of these results will have to be made for different large scale DAF processes.

Influence of particle size

The results of the removal of different activated carbon particle size fractions by the DAF process is relevant in the selection of a size fraction for experimental purposes. It could also serve to indicate which particle size fractions of a typical powdered carbon contribute most to residual turbidity after the PACDAF process, in other words the fraction which is most resistant to removal.

Figures 4-11 and 4-12 confirm experimental observations that the particle size fractions larger than 56 microns are not actually influenced by coagulation. In fact these fractions were removed predominantly by settling and not by DAF, so that a PAC used in the PACDAF process should preferably contain a minimum of particles larger than 50 microns.

4.2 Adsorption efficiency of coagulated powdered carbon

4.2.1 Experimental considerations

Adsorption Isotherms

The adsorption capacity of PAC was determined by means of adsorption isotherms which permit the determination of a functional equilibrium relationship between the residual adsorbate in a batch reactor (liquid phase concentration) and the amount of adsorbate loaded onto the activated carbon (solid phase concentration). Isotherms were performed in a standard manner according to the so-called "bottle-point" method (25), in which flasks containing similar volumes of an appropriately buffered solution of organic adsorbate (phenol and DBS) are each agitated with a different mass of PAC until equilibrium has been achieved. The residual liquid phase concentration in each flask is then measured and the solid phase concentration is calculated by means of a mass balance over the flask. In many cases two initial adsorbate concentrations were used to gain a wider spread of liquid phase concentrations within an acceptable range of experimental accuracy.

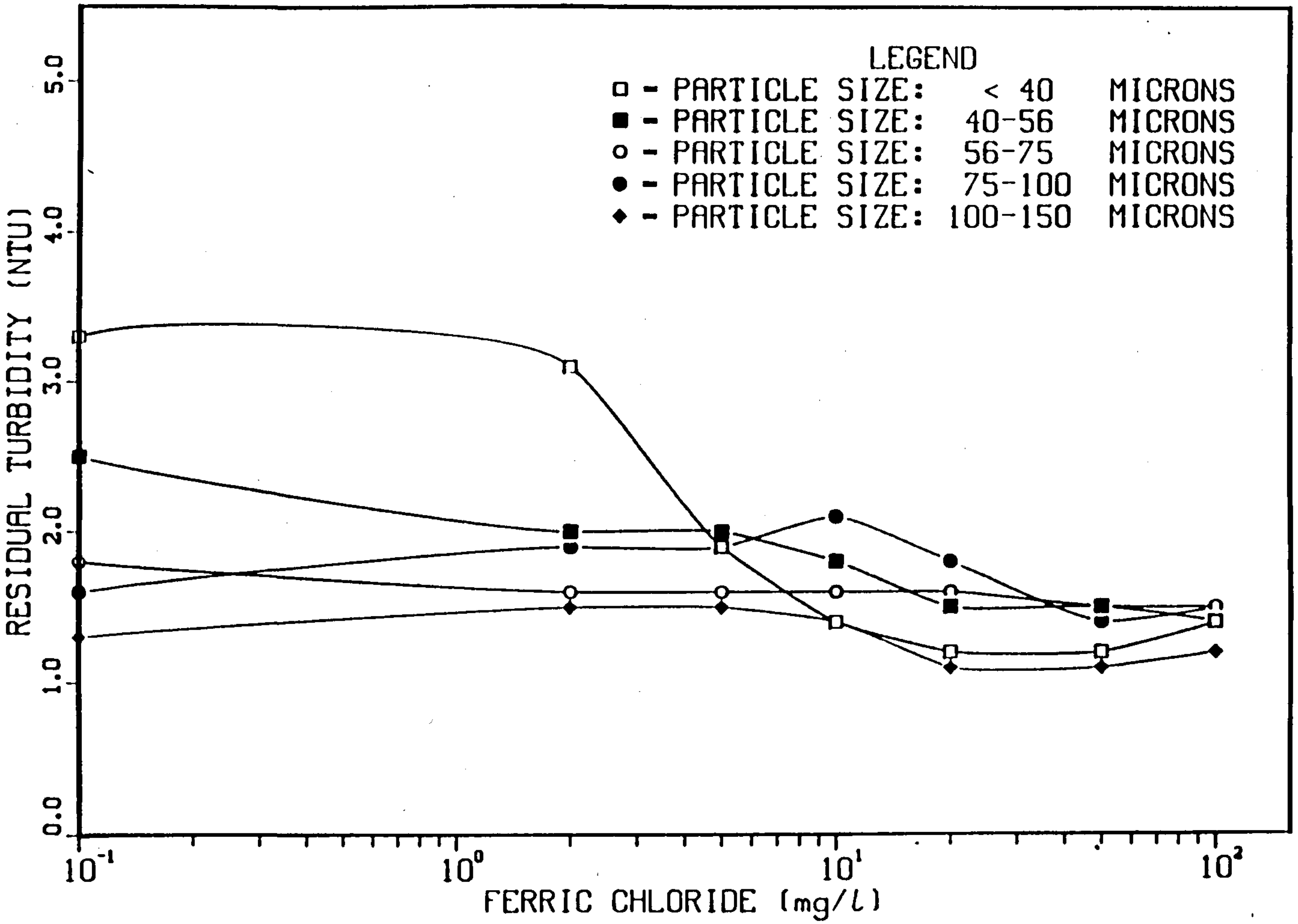


FIGURE 4-11
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Influence of PAC particle size

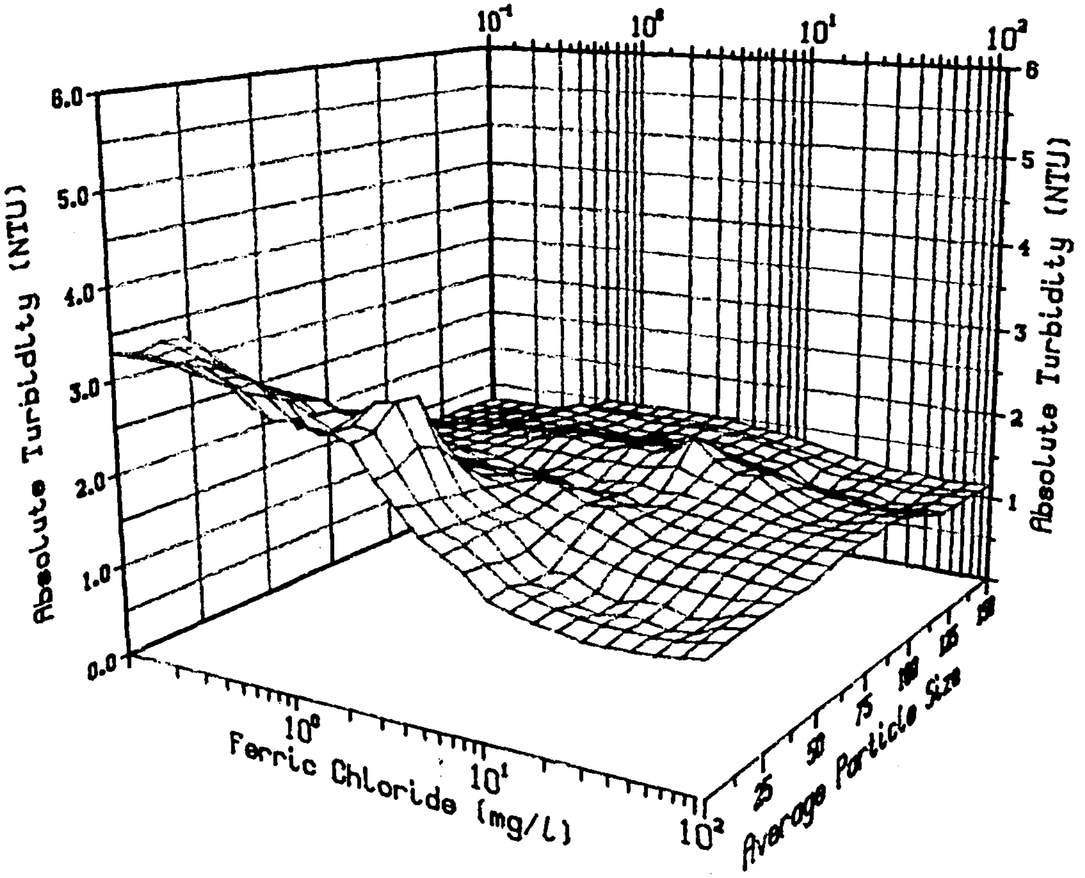


FIGURE 4-12
REMOVAL OF POWDERED ACTIVATED CARBON BY DISSOLVED AIR FLOTATION
Influence of PAC particle size

The effect of coagulation on the adsorption capacity was determined by first flocculating the PAC with different amounts of the coagulants alum, ferric chloride and cationic polyelectrolyte in the manner described for the DAF experiments (Section 4.1.1). After flotation of the flocculated PAC, the subnatant was drained and the residue was carefully transferred into a 250 mℓ Erlenmeyer flask containing the organic adsorbate solution. The flasks were agitated for 96 hours which was considered adequate for the attainment of equilibrium. Where possible the results were modelled by application of the Freundlich isotherm model.

Kinetic experiments

Kinetic experiments on the adsorption rate of the various particle sizes of activated carbon indicated that powdered carbon (below 40 microns sieve fraction) did not display a regular kinetic curve, but rather a sudden drop followed by a very gradual decline (30). For these studies a particle size fraction of 180-250 microns (particle diameter) was found to yield a smooth kinetic curve. The activated carbon employed was Filtrasorb 300 from Chemviron, grounded lightly in a ball mill and sieved to obtain the desired fraction.

The carbon was boiled twice in distilled water and dried overnight at 110 °C before being weighed into exactly 450 mg portions for each experiment. The weighed carbon was soaked overnight in a buffered (0,002 M NaHCO3) solution to remove all air from the pores. A cylindrical stainless steel batch reactor and a liquid volume of 3 000 mℓ was used in all kinetic experiments. Sampling was done by withdrawal of 10 mℓ liquid from the reactor by syringe and discharging it into the sample container via a 45 micron Millipore membrane filter contained in a filter holder attachable to the nozzle of the syringe. This procedure prevented any abraded carbon powder from continuing its adsorption activity once the sample had been taken.

In order to establish the effect of flocculation on the rate of activated carbon adsorption, the pre-soaked carbon was flocculated with the selected coagulant in 2 700 mℓ of adsorbate-free buffered solution of deionized water. Due to the small size of the impeller, flask mixing was conducted at 800 rpm for a minute and slow mixing at 60 rpm for 10 minutes. The rather large carbon particles expectedly displayed a tendency to settle under gravity, but the procedure was adequate for the purpose coating the granules with coagulant. The remaining 10% of the liquid solution containing concentrated adsorbate (10 times the desired concentration) was added at zero time and thereafter samples were withdrawn periodically as described. The initial adsorbate concentration could never be measured in the reactor without the presence of activated carbon, and consequently the initial concentration of the control (unflocculated activated carbon) was used throughout.

4.2.2 Influence of coagulation on adsorption capacity

The isotherms obtained from the adsorption capacity experiments discussed in Section 4.2.1 are displayed in Figures 4-13 to 4-20. Figure 4-13 is an isotherm for phenol adsorption by unflocculated activated carbon and Figure 4-17 is a similar control isotherm for DBS adsorption. A Freundlich isotherm model was fitted to the control isotherms and for ease of comparison, this model was superimposed on the isotherms with flocculated activated carbon. No models were fitted to these isotherms, since there is documented experimental evidence (31) that competitive two-component isotherms do not necessarily fit the same model as the single component isotherm. The Freundlich isotherm model results in a straight line when plotted on logarithmic axes, and Figures 4-21 to 4-28 are plotted in this manner. As before, the control isotherm is included in each graph for comparative purposes.

From the results it appear that the influence of alum and ferric chloride flocculation on the adsorptive capacity of the activated carbon is slight and is considered insignificant in comparison with the experimental scatter. The influence of flocculation with cationic polymer is substantially greater, and the isotherm tends to become non-linear and solid phase concentrations are proportionally lower at increased liquid phase concentrations. This effect was reported and discussed by Frïck and Sontheimer (31) and is similar to the competitive effect of a relatively stronger adsorbate on the isotherm of a relatively weaker one.

It can therefore be concluded for the adsorbate adsorbent systems under study that coagulation by alum and ferric chloride has no marked effect upon the adsorption capacity of the powdered activated carbon, whereas the cationic polymer did reduce

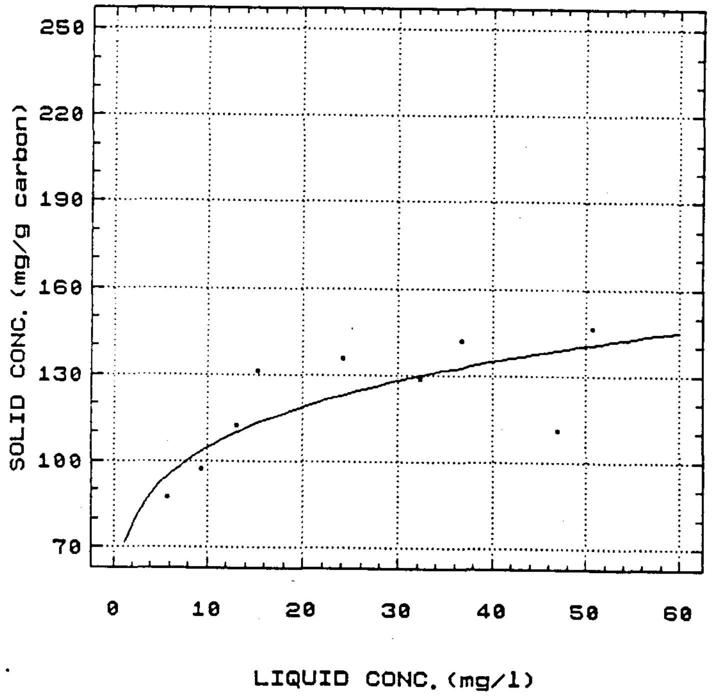


FIGURE 4-13
FREUNDLICH ISOTHERM FOR PHENOL
No coagulant added

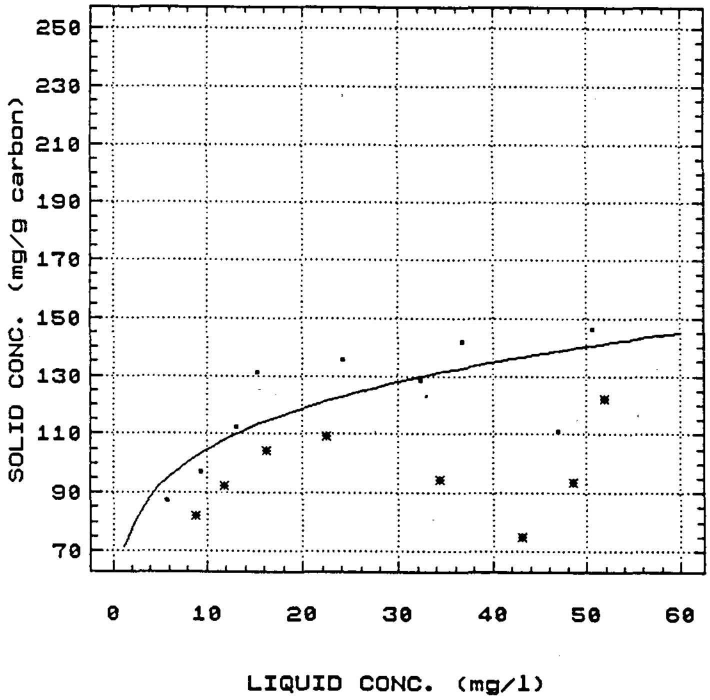


FIGURE 4-14
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l ferric chloride

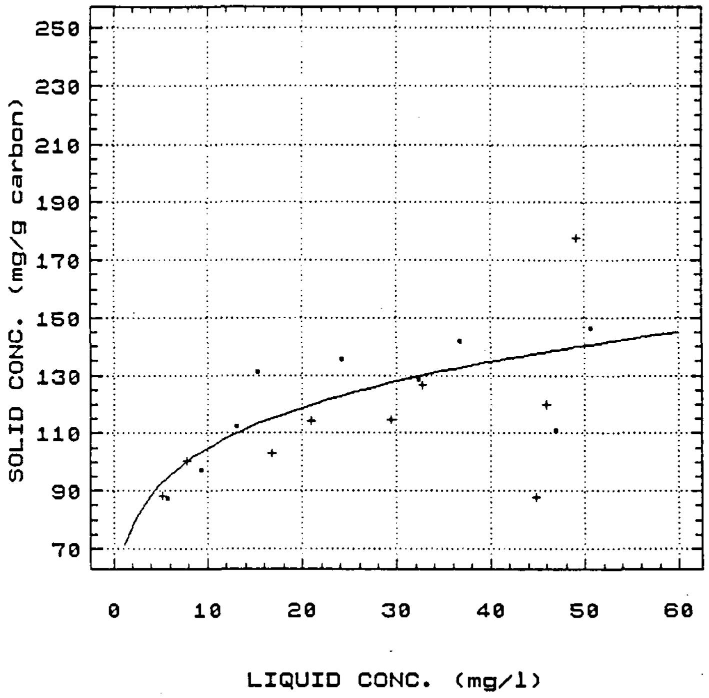


FIGURE 4-15
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l aluminium sulphate (alum)

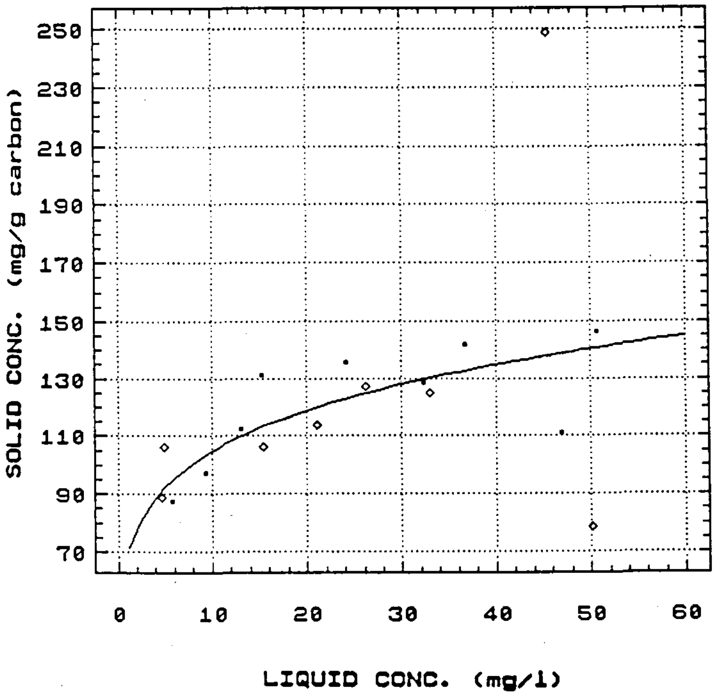


FIGURE 4-16
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l cationic polyelectrolyte

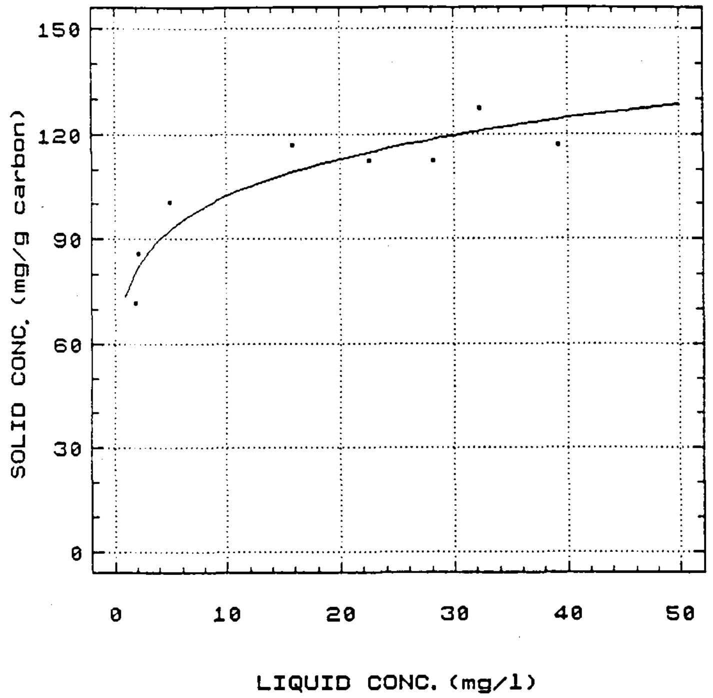


FIGURE 4-17
FREUNDLICH ISOTHERM FOR DBS (dodecylbenzenesulphonate)
No coagulant added

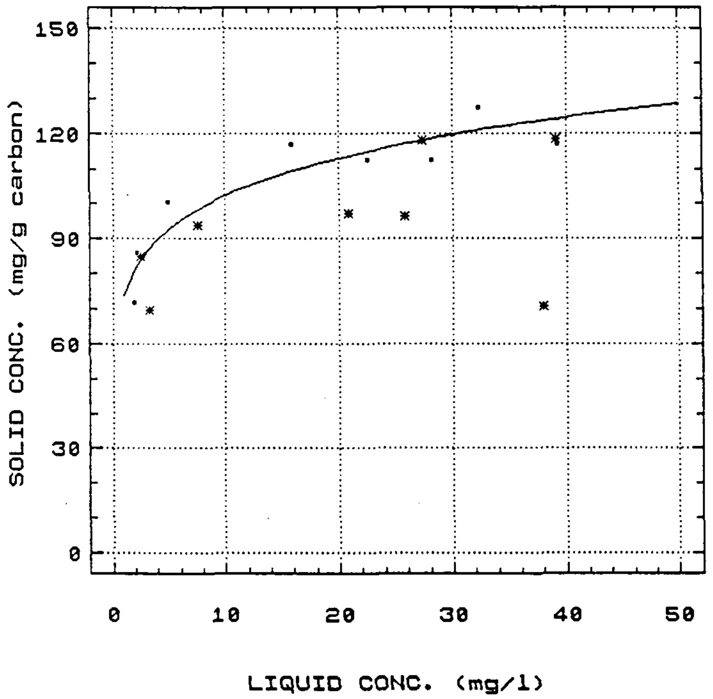


FIGURE 4-18
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l ferric chloride

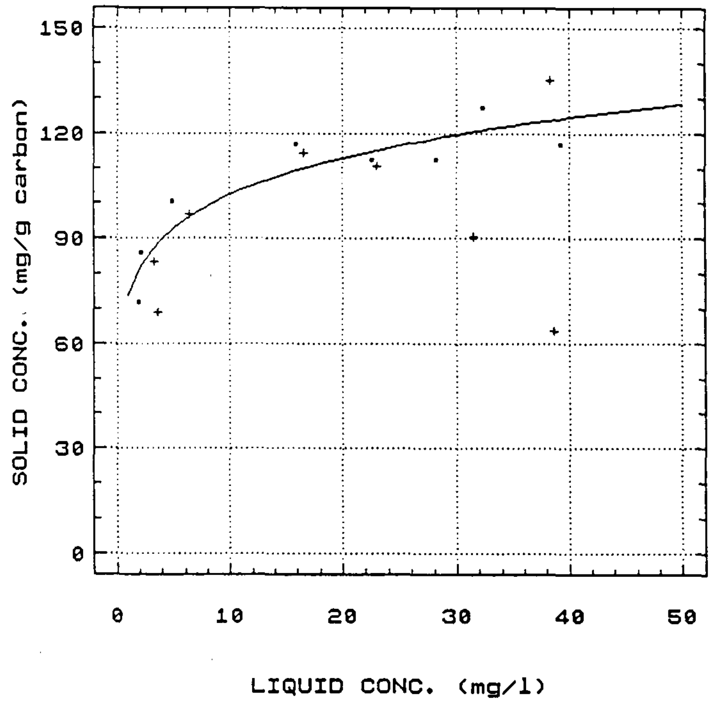


FIGURE 4-19
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l aluminium sulphate

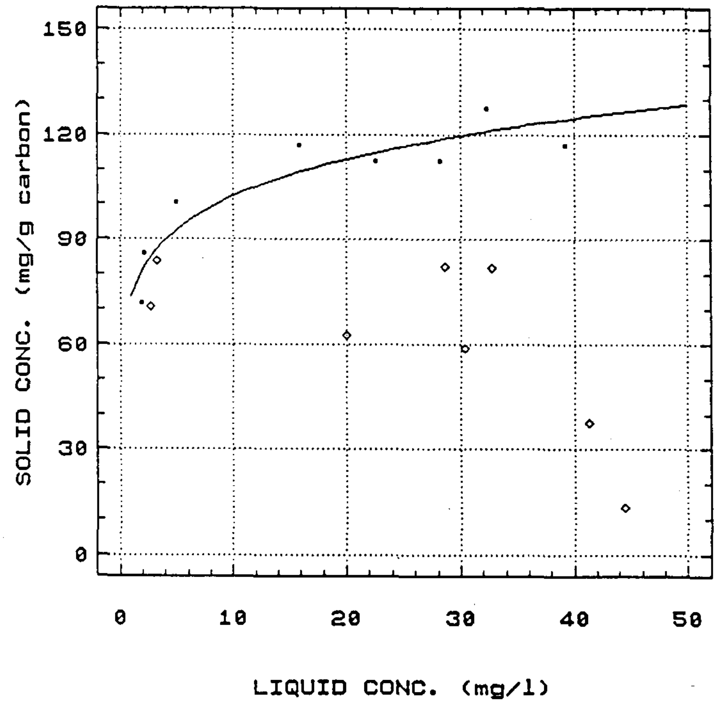


FIGURE 4-20
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l cationic polyelectrolyte

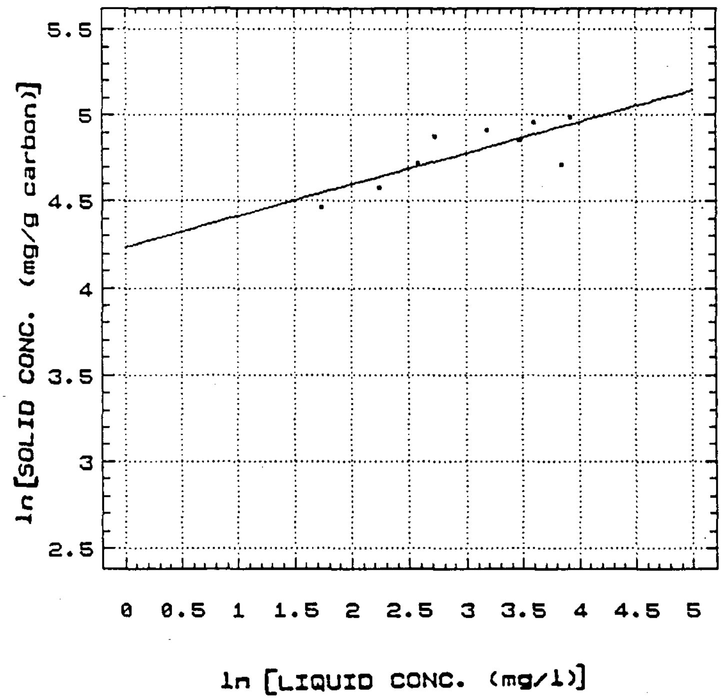


FIGURE 4-21
FREUNDLICH ISOTHERM FOR PHENOL
No coagulant added

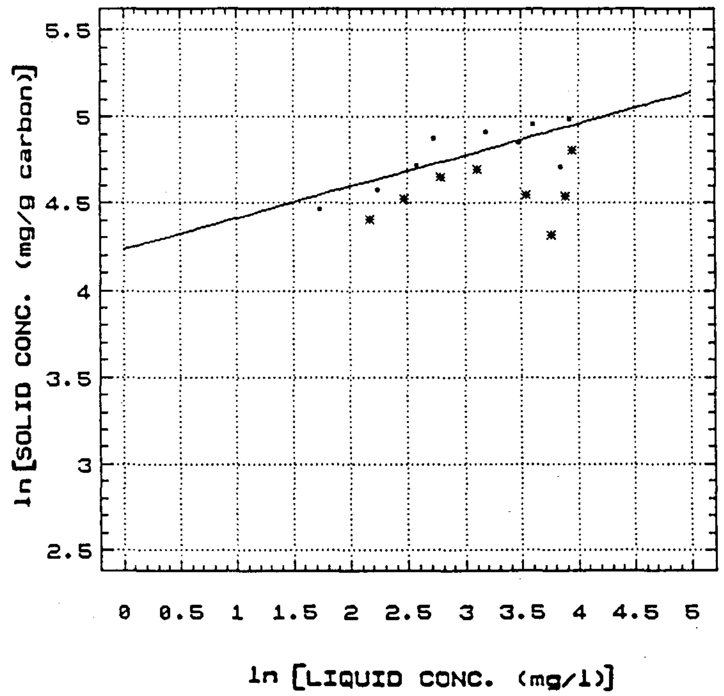


FIGURE 4-22
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l ferric chloride

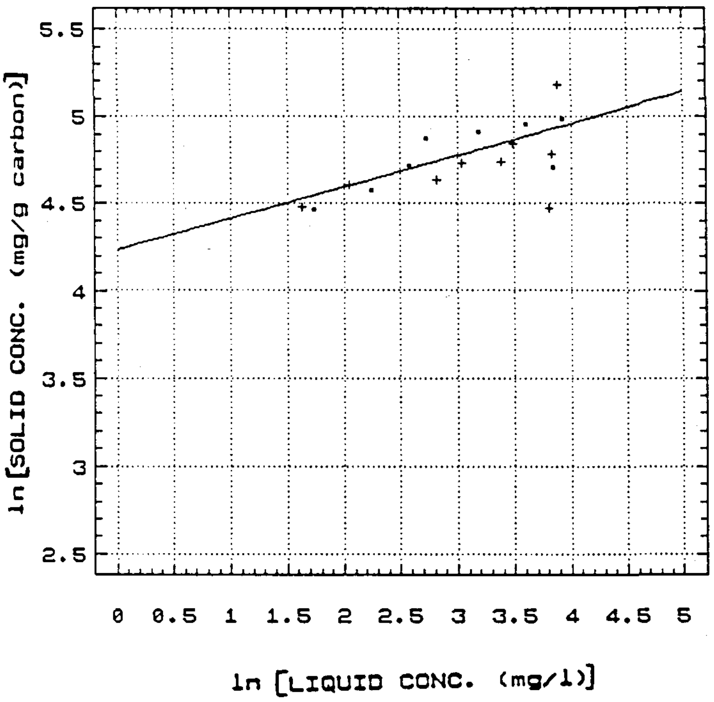


FIGURE 4-23
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l aluminium sulphate

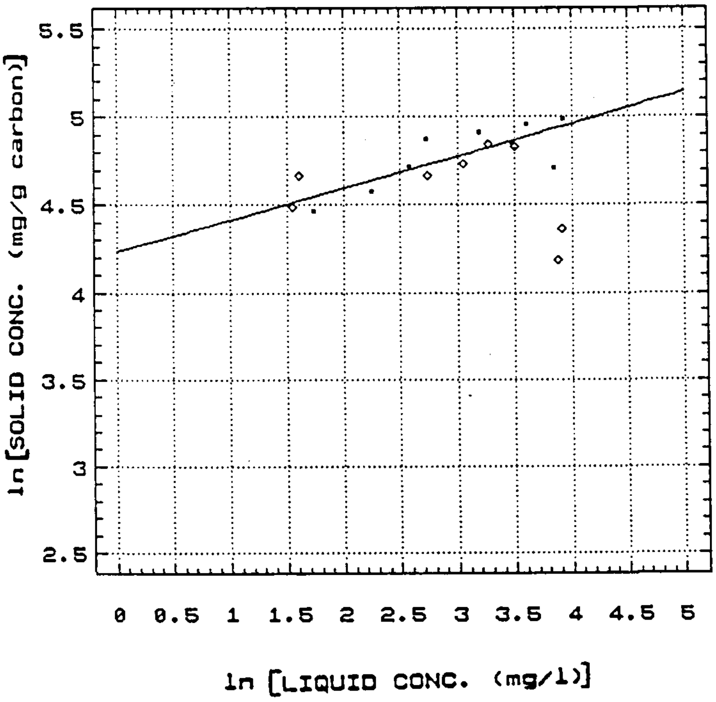


FIGURE 4-24
FREUNDLICH ISOTHERM FOR PHENOL
After coagulation with 50 mg/l cationic polyelectrolyte

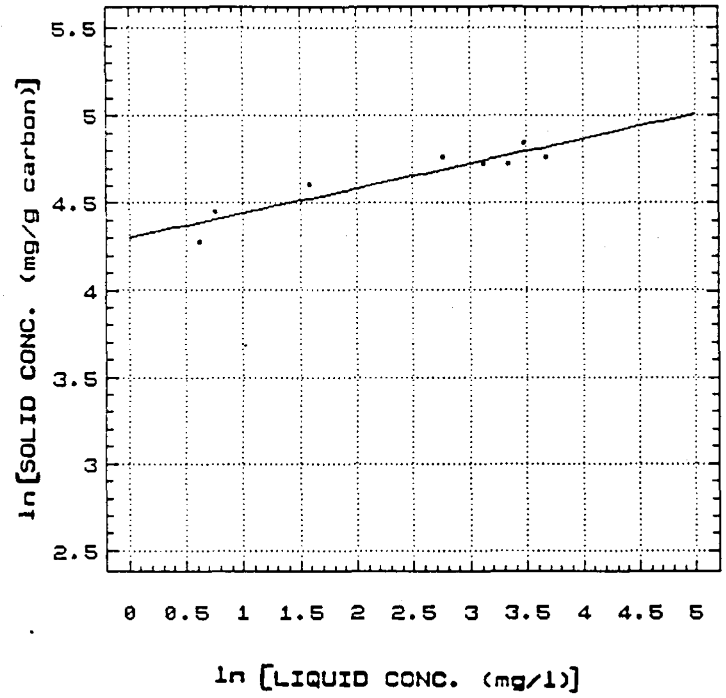


FIGURE 4-25
FREUNDLICH ISOTHERM FOR DBS
No coagulant added

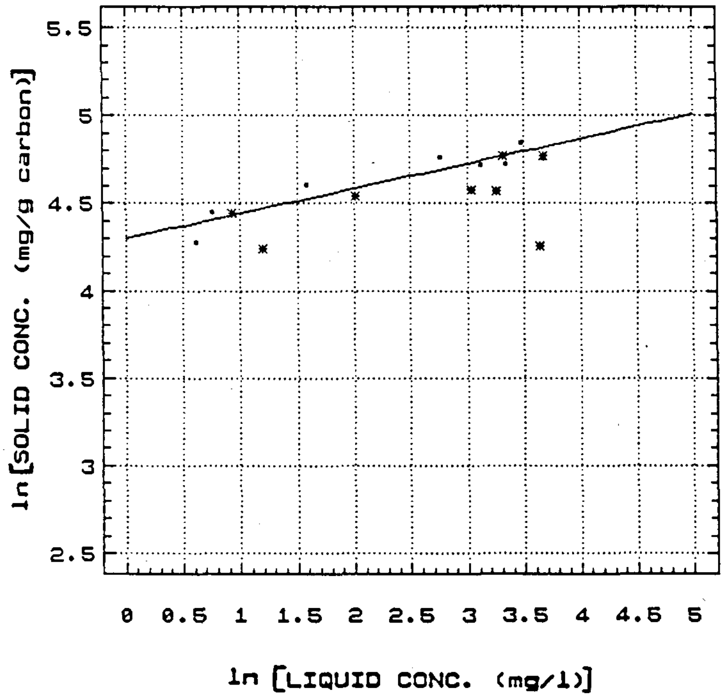


FIGURE 4-26
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l ferric chloride

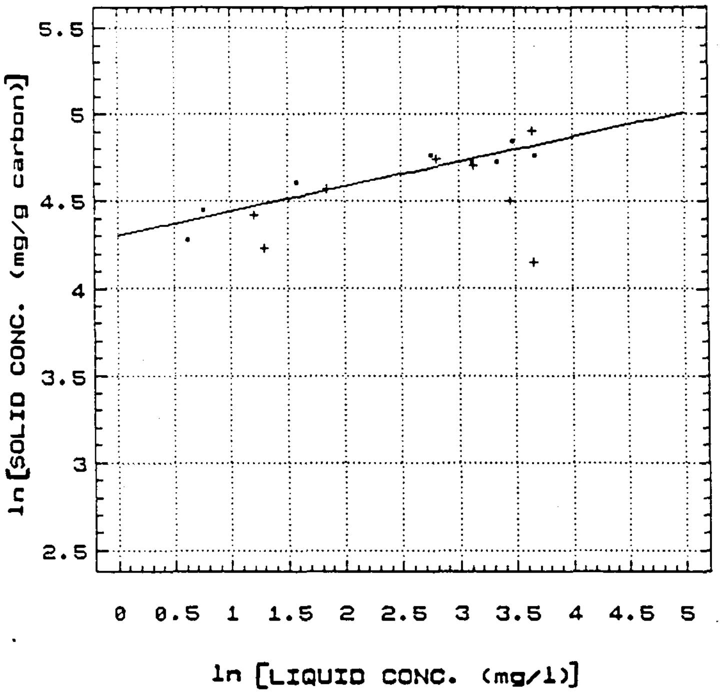


FIGURE 4-27
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l aluminium sulphate

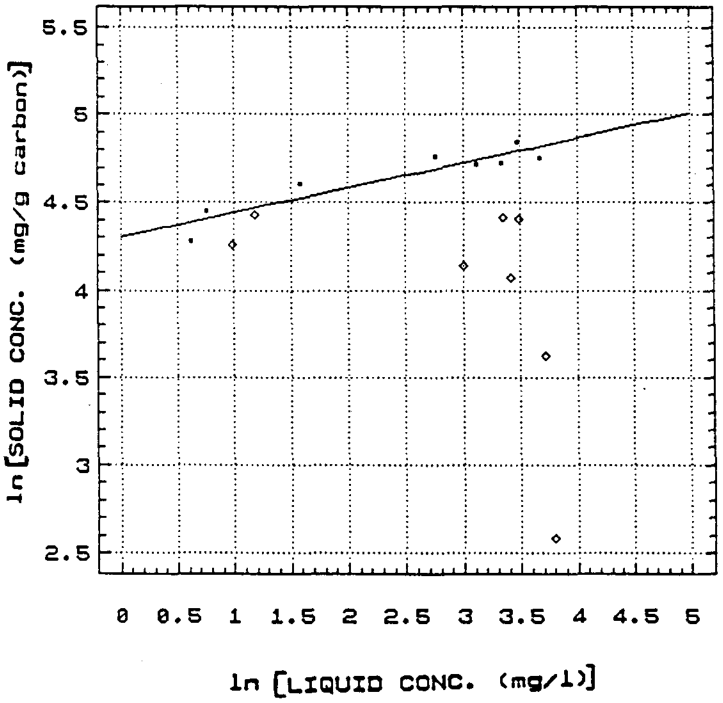


FIGURE 4-28
FREUNDLICH ISOTHERM FOR DBS
After coagulation with 50 mg/l cationic polyelectrolyte

adsorption capacity. This result is encouraging for the application of PAC in the two-stage counter-current PACDAF system in which flocculated PAC is transferred from the second to the first reactor counter-current to the flow of feed water through the system.

4.2.3 Influence of coagulation on adsorption rate

The results of the experimental work performed in accordance with the methods described in Section 4.2.1 are displayed in Figures 4-29 and 4-30. These figures indicate the influence of increasing ferric chloride concentrations on the adsorp-tion rate of a fine granular activated carbon for phenol and DBS respectively. The adsorbate concentration in each case is expressed in the dimensionless form (adsorbate concentration at a certain time divided by the initial adsorbate concentration) to facilitate comparison, and initial adsorbate concentrations of 30 mg/ℓ were used in each case.

The results indicate that increasing coagulant concentrations have an adverse effect on the removal rate of both adsorbates from solution. However, the effect is not so marked in the case of lower coagulant concentrations as to constitute a serious problem in practice. These results are not for powdered carbon, but nevertheless serve as an indication that coagulation by ferric chloride should not drastically impair the adsorption efficiency of an activated carbon when used in the proposed counter-current PACDAF system.

4.3 Adsorption efficiency of various paricle sizes of activated carbon

Adsorption isotherms and kinetic experiments

All adsorption experiments were conducted using various size fractions of Flitrasorb 300 activated carbon (Chemviron). The activated carbon was grounded and sieved into fractions larger than 425 µm using an Endecott Test Sieve shaker. The fraction below 425 ℓ were dry separated, using an Alpine (Type A320 LS) vacuum suction apparatus, and collected for the experiment. The fraction below 20 µm was descarded and six fractions were collected between 20 and 250 µm at intermediate cut-off points

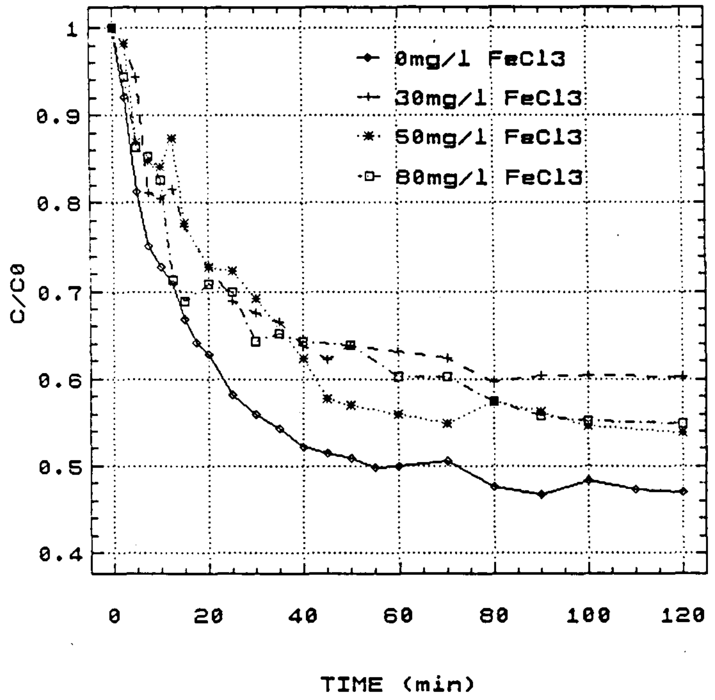


FIGURE 4-29
BATCH REACTOR KINETIC TESTS FOR THE REMOVAL OF PHENOL
Effect of different concentrations of ferric chloride coagulant
Phenol initial concentration: 30 mg/l

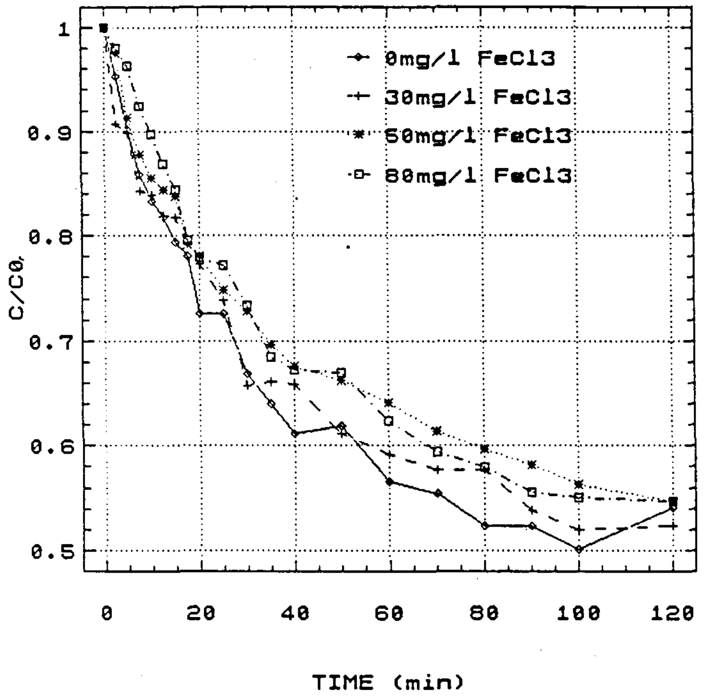


FIGURE 4-30
BATCH REACTOR KINETIC TESTS FOR THE REMOVAL OF DBS
Effect of different concentrations of ferric chloride coagulant
DBS initial concentration: 30 mg/l

of 40, 56, 75, 100 and 150 μm. These fractions were used in all isotherm and kinetic experiments. The isotherm tests were conducted according to the method described in section 4.2.1.

Kinetic experiments were conducted in a cylindrical baffled stainless steel vessel fitted with a paddle agitator extending obliquely into the vessel from above and operated at a rate of 800 rpm.

Influence of particle size on equilibrium capacity

Isotherms for phenol were determined for each of the six different particle size fractions of activated carbon. Freundlich isotherms were fitted to the data by linear regression on the natural logarithms of the liquid and solid phase concentrations. These isotherms are displayed in Figure 4-31 and the Freundlich constant and exponent for the isotherm of each particle size fraction are given in Table 4-2.

Table 4-2 : Freundlich isotherm parameters for phenol

Carbon particle size fraction μm	Freundlich isotherm		Correlation coefficient
	constant	exponent	
425 - 600	47,8	0,317	0,9099
150 - 250	50,7	0,316	0,9667
100 - 150	42,6	0,375	0,9768
75 - 100	50,4	0,310	0,9764
40 - 56	45,5	0,330	0,9646

It appears that there is no clear trend relating the carbon particle size to either the Freundlich constant or the exponent and the Freundlich parameters were determined as 48.38 and 0.317 for the constant and exponent respectively. The independance of isotherm parameters of carbon particle size tends to support findings of the majority of researchers (35,36) and indicates that grinding of the carbon does not affect adsorption capacity.

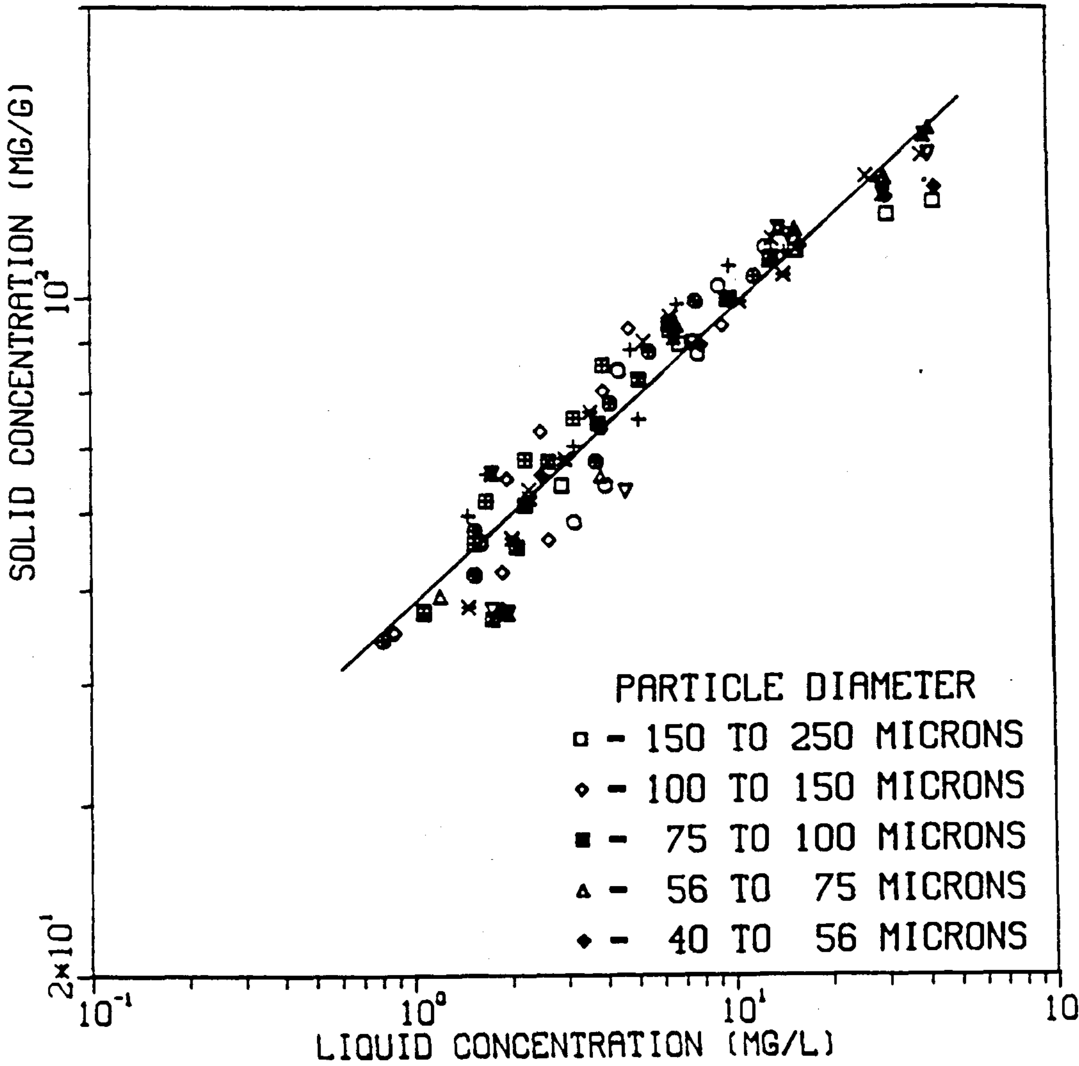


FIGURE 4-31
FREUNDLICH ISOTHERM FOR PHENOL
All particle size fractions included

Influence of particle size on adsorption rate

Kinetic batch reactor experiments were performed on DBS over time periods of 120 minutes. The data for the different particle size fractions on the adsorption rate curves for DBS is displayed in Figure 4-32 and indicates clearly the effect of adsorbent paricle size on the adsorption rate profile. For a powdered activated carbon, a large percentage of the partcle sizes are typically below even the smallest range investigated in this study and a very sharp initial drop in concentration can be expected (32). The relatively bulky DBS molecule is adsorbed comparitively slowly and after 120 minutes none of the particle size fractions had achieved more than 35% removal, which constitutes less than half of the equilibrium capacity of the carbon for DBS.

4.4 Influence of activated carbon particle size on its settling performance

Figures 4-33 and 4-34 show the settling behaviour of four particle size fractions of activated carbon in a sylindrical water column as measured by the turbidity at three sampling ports along the column. The turbidity profiles indicate that particle size fractions below approximately 60 microns settle slowly and after several hours there was still evidence of suspended and probably colloidal powdered carbon in the water. Particle size fractions above 75 microns settled rapidly. Even in these fractions some residual turbidity remained, but this can be ascribed to the fine carbon inevitably generated during the preparation of the fractions.

The results gave a clear indication of the settling characteristics of the various particle size fractions and can be applied to specify the minimum effective size range for use in applications where the carbon is separated from the water by means of gravity or by DAF.

5. PACDAF PILOT PLANT TESTS

5.1 Description of the pilot plant

A primary objective of this research project was to proceed with pilot scale research on the powdered carbon/dissolved air flotation (PACDAF) system. Based on the

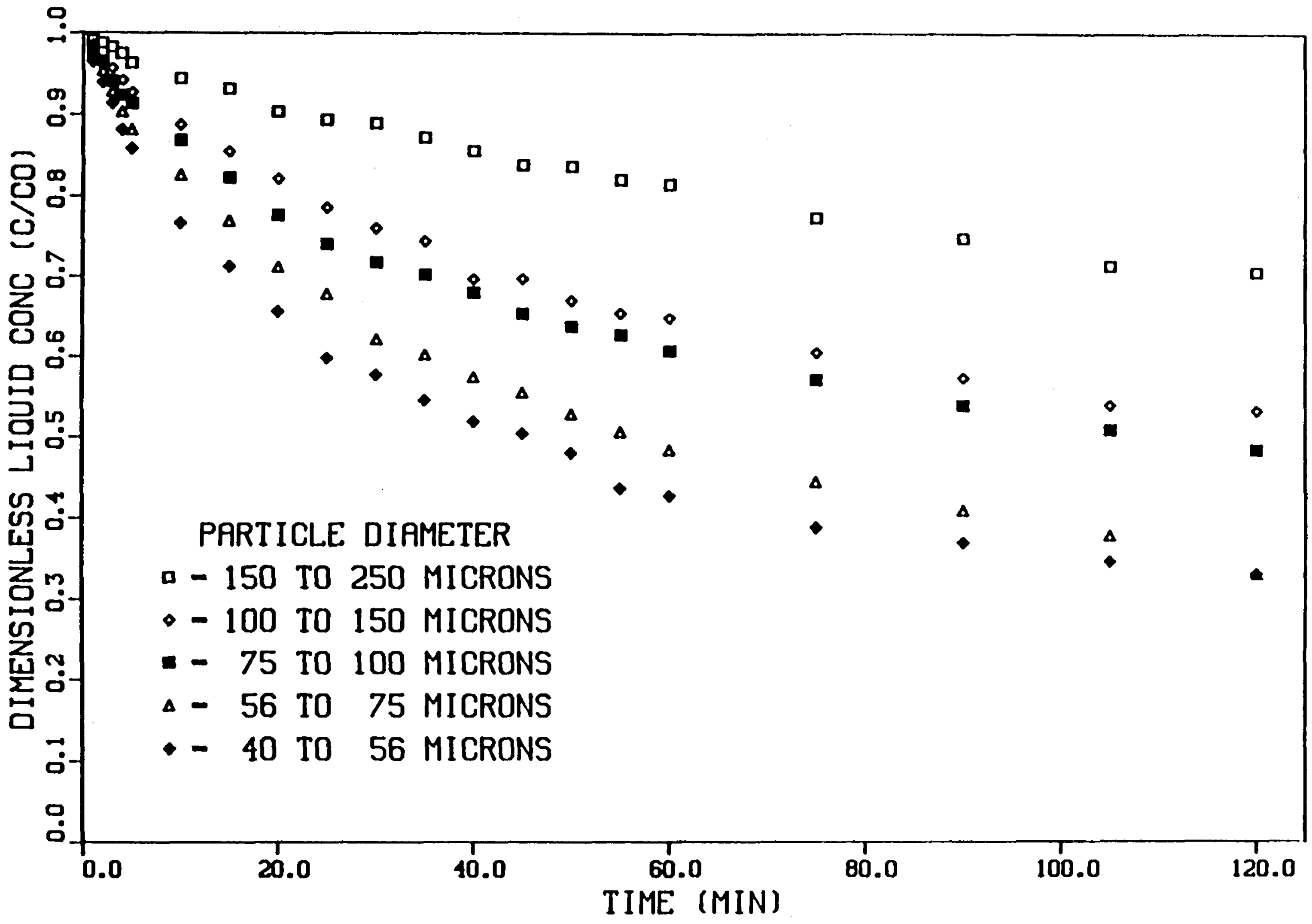
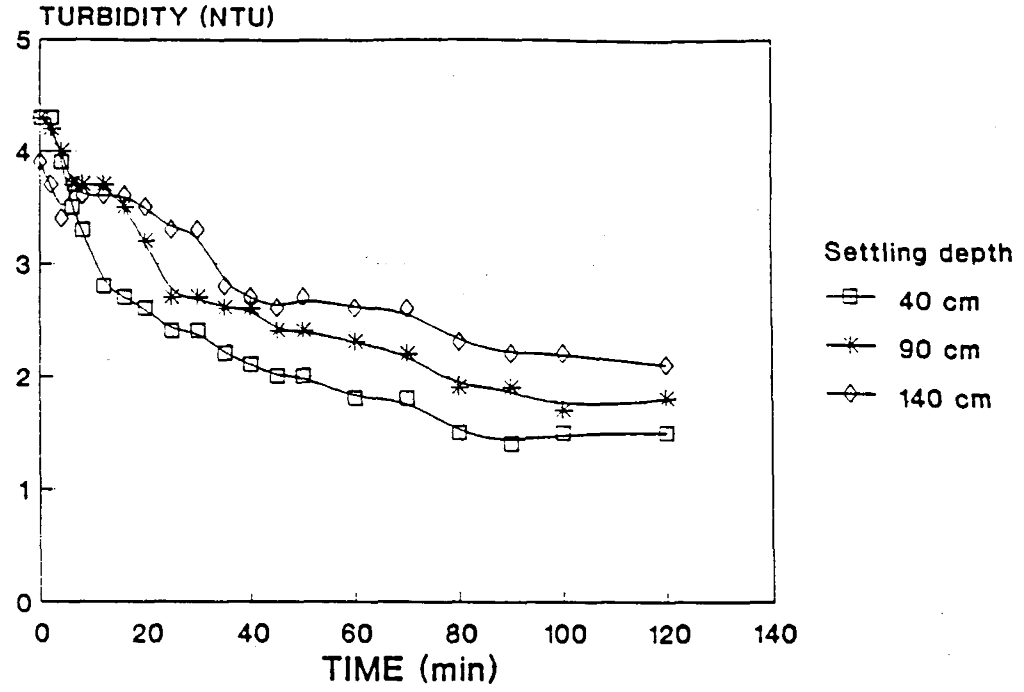
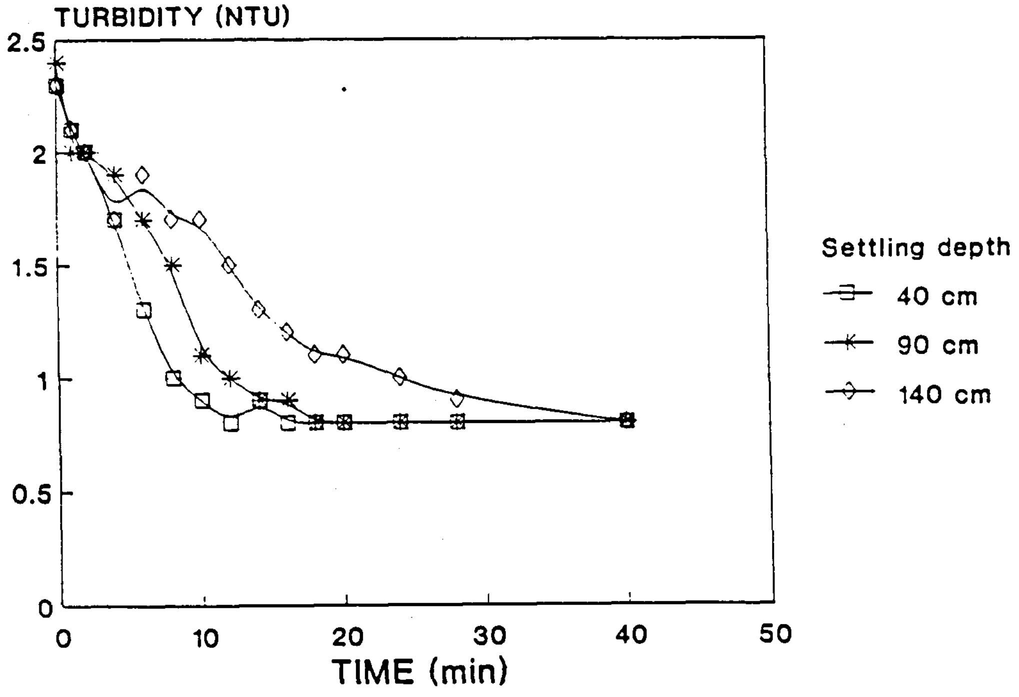


FIGURE 4-32
KINETIC ADSORPTION CURVES
DBS adsorption by different activated carbon particle size fractions

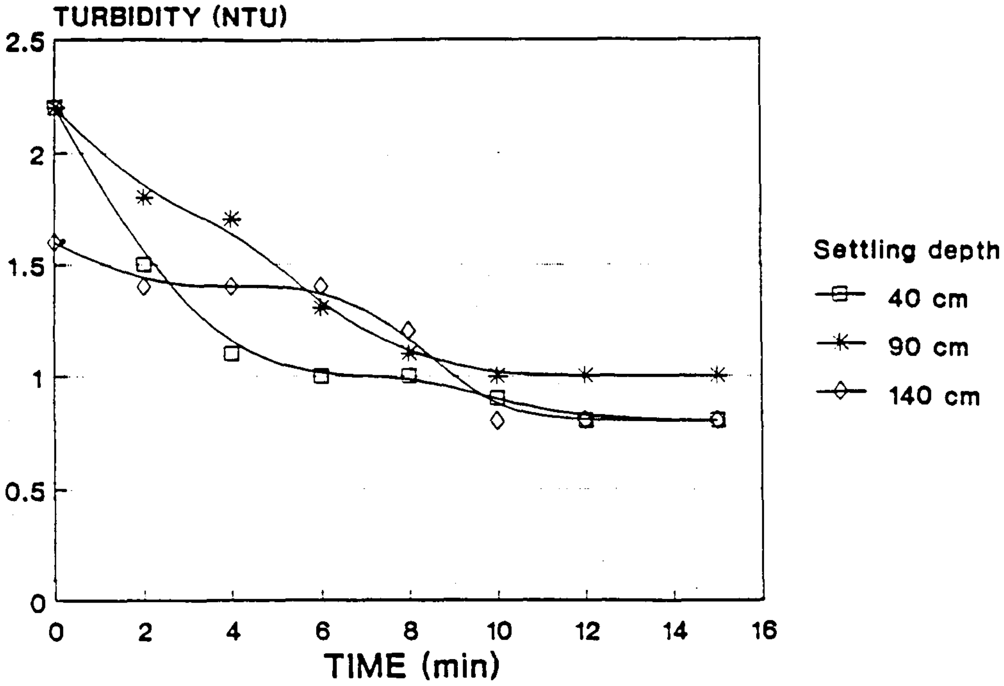


Particle size fraction: 40 - 60 micron

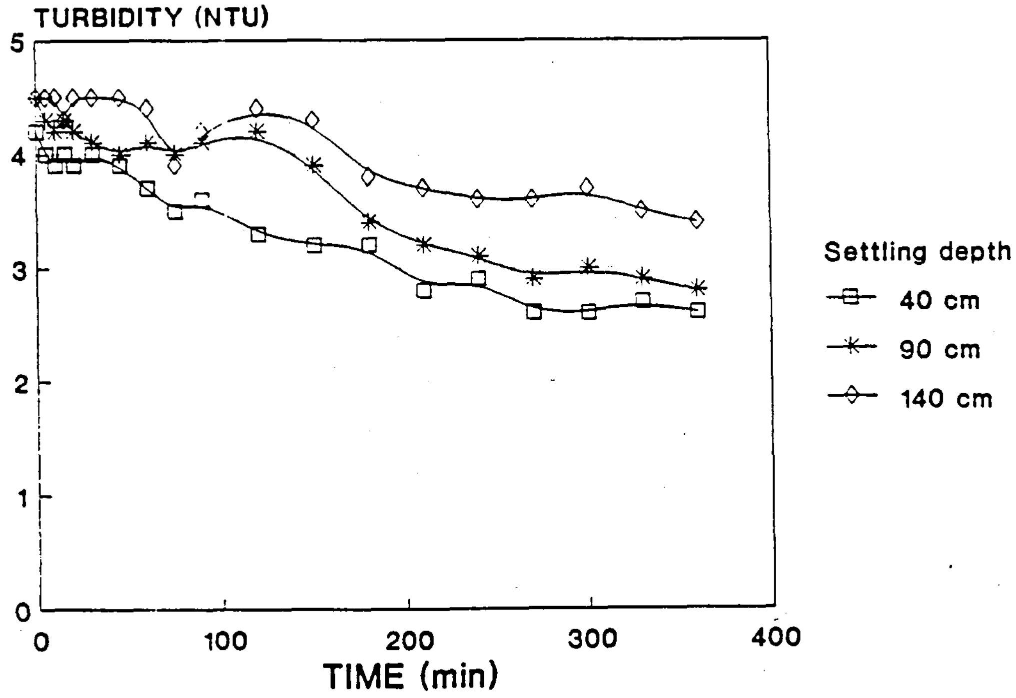


Particle size fraction: 75 - 100 micron

FIGURE 4-33
SETTLING RATES OF TWO PARTICLE SIZE FRACTIONS
Application to initial 10 minutes and to 120 minutes adsorption period



Particle size fraction: 100 - 150 micron



Particle size fraction: 20 - 40 micron

FIGURE 4-34
SETTLING RATES OF TWO PARTICLE SIZE FRACTIONS
Application to initial 10 minutes and to 120 minutes adsorption period

theoretical illustration in section 3, and literature (26), as well as utilizing the PAC to its full potential, a two stage reactor PAC system was constructed. This counter-current PACDAF pilot plant is mobile, so that problematic waters can be treated at their sources.

In the counter-current PACDAF pilot plant system, powdered activated carbon (PAC) is separated from the water by dissolved air flotation (DAF). DAF is also used to remove algae and other suspended matter present in the raw water, so that the DAF stages serve two purposes. The use of DAF for PAC removal is based upon the findings of the laboratory scale PAC removal experiments (See 4.1).

The system is shown schematically in Figure 2-2, which illustrates the principles of the counter-current PACDAF unit. Fresh PAC is added to the second reactor or contact tank to polish the partially treated effluent from the first reactor's DAF separator. PAC with a relatively low adsorbate loading is then removed from the process stream by coagulation, flocculation and DAF, and the product water leaves the system to be treated by final filtration. The flocculated PAC is recirculated to the first reactor and brought into contact with algae-laden raw water. The exhausted PAC and flocculated algal biomass is then separated by DAF and discharged from the system, whilst the clear product water passes to the second reactor. In this way, product water and PAC pass through the system in a counter-current mode.

The system is illustrated schematically in greater detail in Figures 5-1 and 5-2, in which the operations of the various unit processes of the system are illustrated. The stirred adsorption reactors of the two stages were designed with retention times of 6,5 minutes each and the plant was designed for a flow rate of 10 kℓ/day (0,116 ℓ/s).

The first contact tank receiving the partially used PAC and the raw water is provided with a paddle stirrer operating at 52 rpm). An Induna 1,1 kW centrifugal pump (operating at 2 900 rpm) pumps the process stream from the contact tank through a rotameter after which flocculants (alum or ferric chloride, with or without polyelectrolyte flocculation aids) are added. An in-line static mixer (Kenics) for a Reynolds number (Re) greater than 2 000 is used for flash mixing before the stream is introduced into the first of two flocculation chambers. These chambers are equipped with paddle

Figure 5-1 : Schematic flow diagram

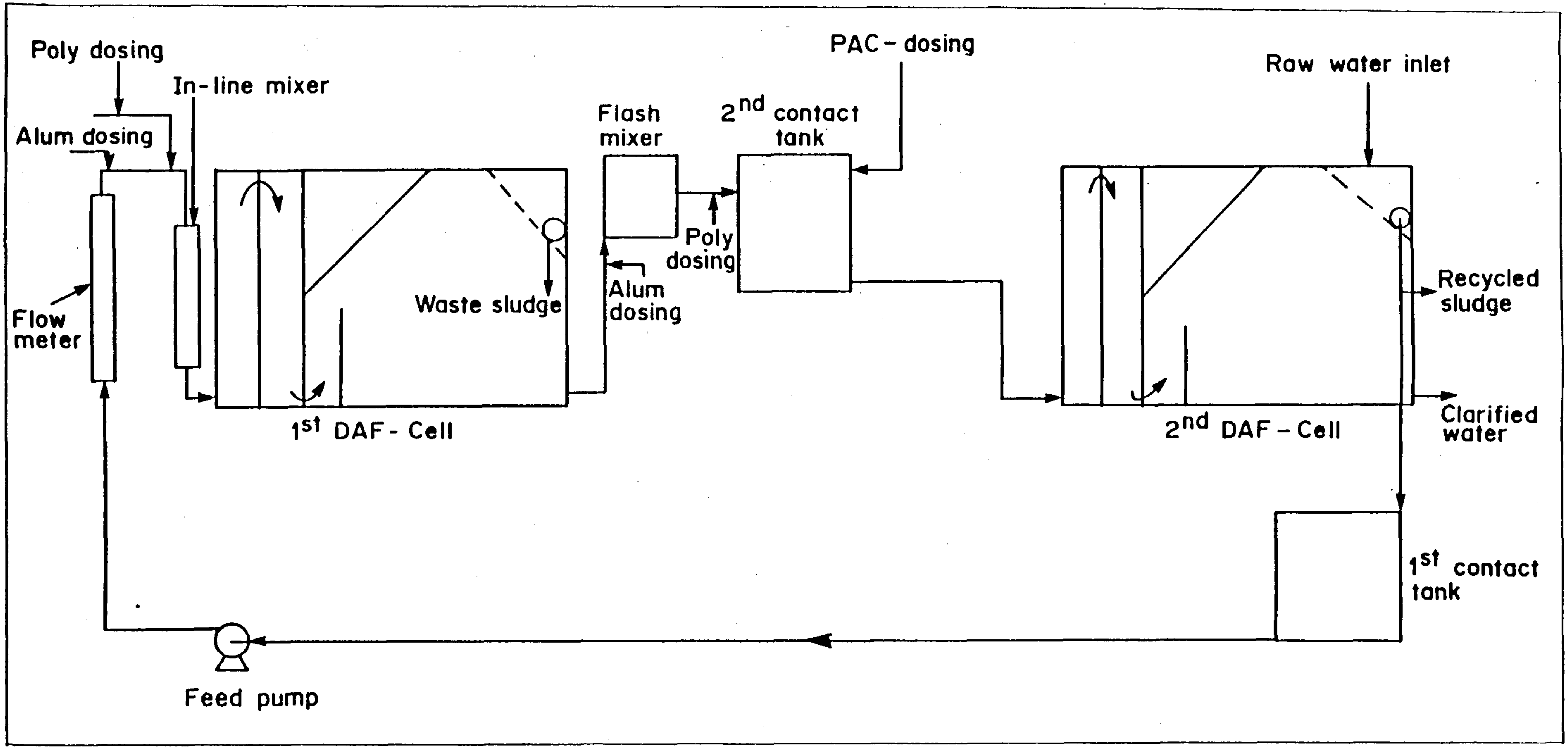
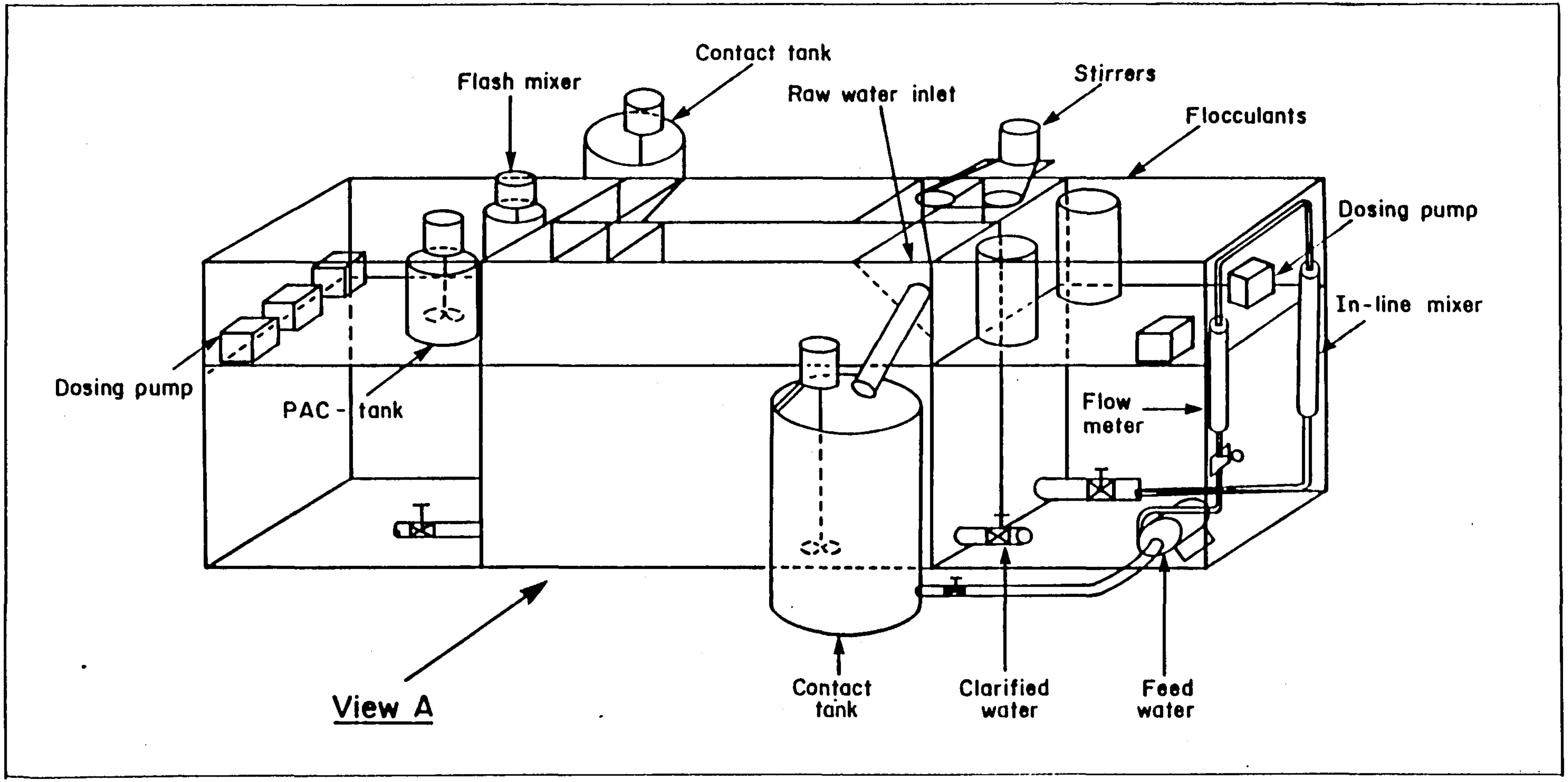


Figure 5-2 : Unit operations



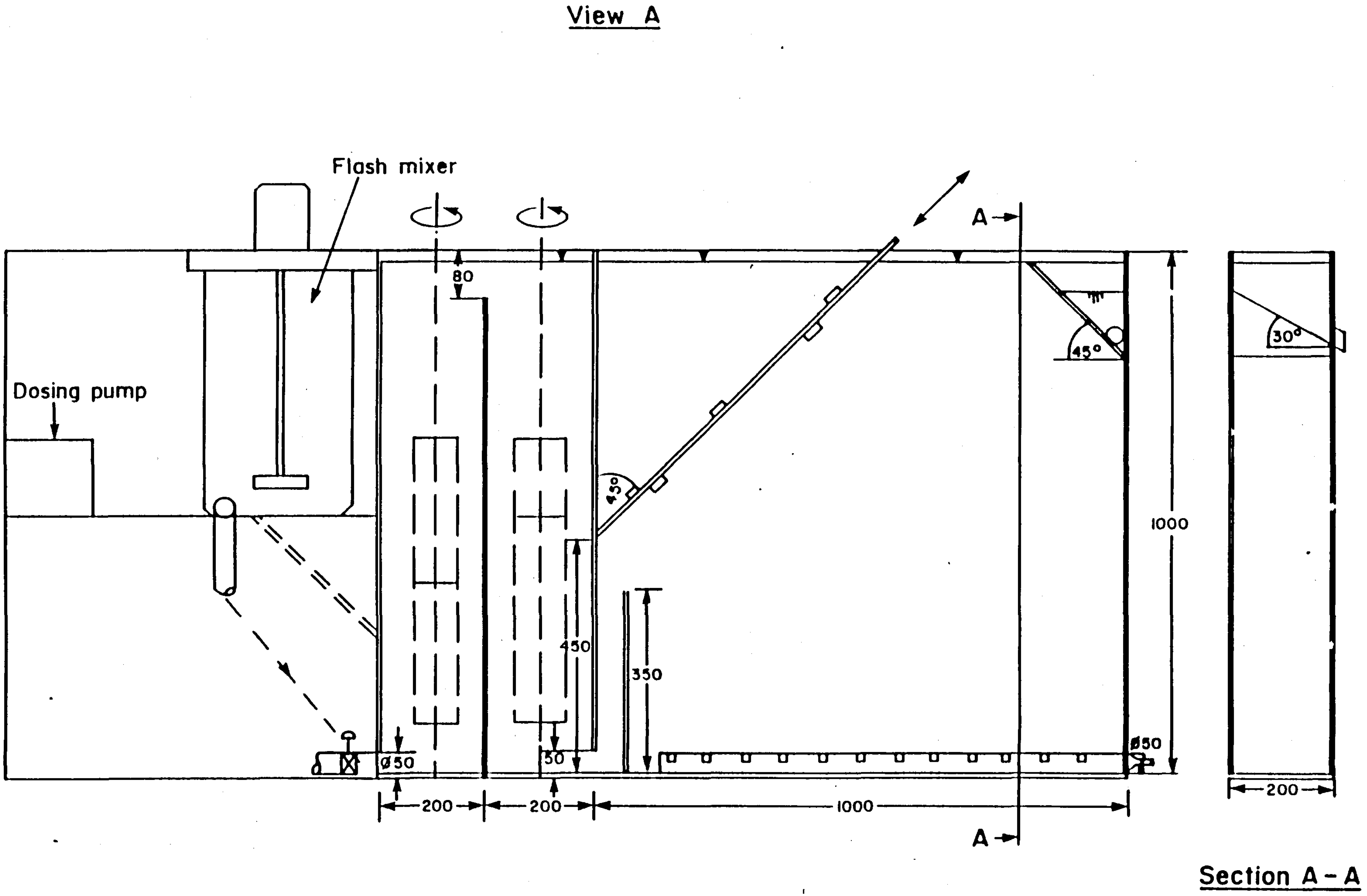


Figure 5-3 : Dimensional details

stirrers (similar to those shown in Figure 5-3) with root mean square velocity gradients (G) of 50,8 s^{-1} and 26,2 s^{-1} respectively and operating at 10,5 rpm and 6,6 rpm. The G-values were calculated according to the methods proposed by Polasek (33). Details of the DAF unit are shown in Figure 5-3, in which all dimensions are given in millimeters.

Clean water charged with dissolved air at a pressure of 400 kPA is introduced via a pin valve at the base of the DAF chamber. A removable baffle plate angled at 45° was designed to concentrate rising flocs in a small water surface area to produce a relatively compact sludge which overflows continuously or periodically into the sludge collection duct as waste sludge. The process stream continues from the withdrawal tube in the bottom of the DAF chamber and flows into a paddle-stirred flash mixer after coagulant has been added. The flash mixer operates at 100 rpm. Fresh PAC is dosed into the second contact tank (6,5 minutes retention time) and the process water then passes to flocculation chambers and the second DAF unit which are identical to those of the first unit. Flocculated PAC sludge overflowing from the second DAF unit, is introduced directly into the first contact tank and clarified water is withdrawn from the bottom of the unit.

5.2 Preliminary laboratory experiments

The objective of the preliminary laboratory studies was to select an appropriate powdered activated carbon for use in the pilot scale PACDAF experiments at the Temba Water Treatment Facility. This study involved three phases :

- analysis of the Temba raw water to find a surrogate concentration parameter;
- determination of an appropriate PAC dosage; and
- selection of an appropriate PAC.

An analysis of the Temba raw water is provided in Table 5-1. This water is fairly turbid and has a high dissolved organic content. The continuous determination of the organic content of the water by means of DOC analysis is considered not only impractical and time consuming, but also prohibitively expensive. It was therefore decided to investigate the use of ultra-violet spectrophotometry as a possible surrogate analysis.

TABLE 5-1: Analysis of Temba raw water on 14 November 1989

Analytical determinand	Value	Unit
Turbidity	4,0	NTU
pH	7,8	
Electrical conductance	72,3	mS/m
Calcium (Ca)	49	mg/ℓ
Magnesium (Mg)	19	mg/ℓ
Iron (Fe)	244	µg/ℓ
Kjehldahl Nitrongen (N)	0,9	mg/ℓ
Total phosphate (P)	2,1	mg/ℓ
Alkalinity ($CaCO_3$)	127	mg/ℓ
Dissolved organic carbon (DOC)	13,3	mg/ℓ

An ultra-violet absorption scan indicated localized absorption maxima at 210, 270, 320, 374 and 380 nm wavelengths. During initial test work using a stirred batch reactor, Temba raw water and Norit SA4 Powdered carbon, it was realized that many of these wavelengths give such poor UV absorption as to make experimental results unreliable. Lower wavelengths tended to give higher UV absorption, but were found to be unspecific with little variation, whereas higher wavelengths often fell outside the range of accuracy of the spectrophotometer.

Edwards and Cressor (34) found statistically significant correlations between UV absorbance at 250 nm and 350 nm and total organic carbon content of river water in two streams in north-east Scotland. They also found that suspended solids had but a small impact on this correlation, which was therefore also valid for DOC measurements. Likewise, DOC analyses at the CSIR's Division of Water Technology are performed at 254 nm. Thus the latter wavelength was selected for further analyses. In addition, the 225 nm wavelength was also selected arbitrarily for its relatively high absorbance.

Batch reactor kinetic tests (2 000 mℓ volume) using Temba raw water were consequently conducted for GS48 powdered carbon (supplied by Floccotan) at dosages of 20, 40, 60, 100 and 200 mg/ℓ. Residual reactor concentration was measured up to three hours of adsorption at UV wavelengths of 225 nm and 254 nm. The results of these experiments are shown in Figures 5-4 to 5-8. It is evident that UV absorbance at 225 nm is substantially less sensitive to adsorption treatment than the

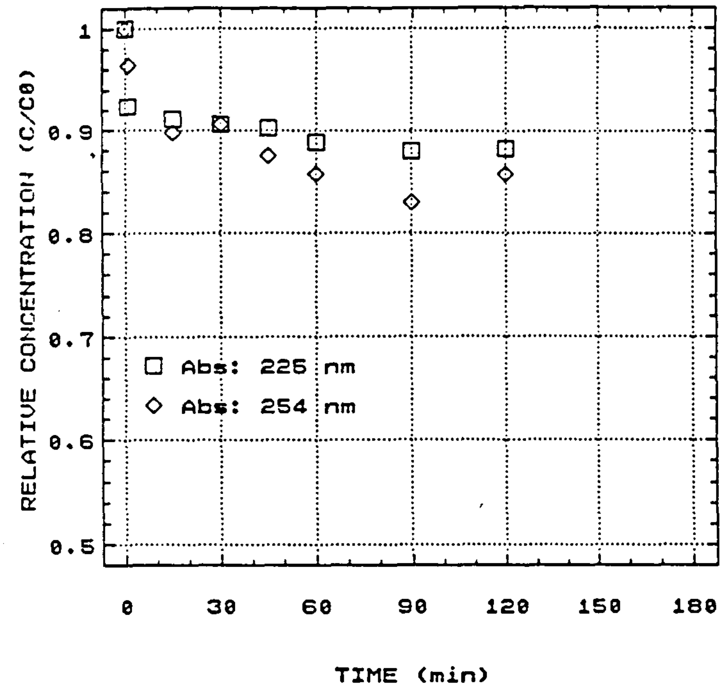


FIGURE 5-4
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
PAC dosage of 20 mg/*l*

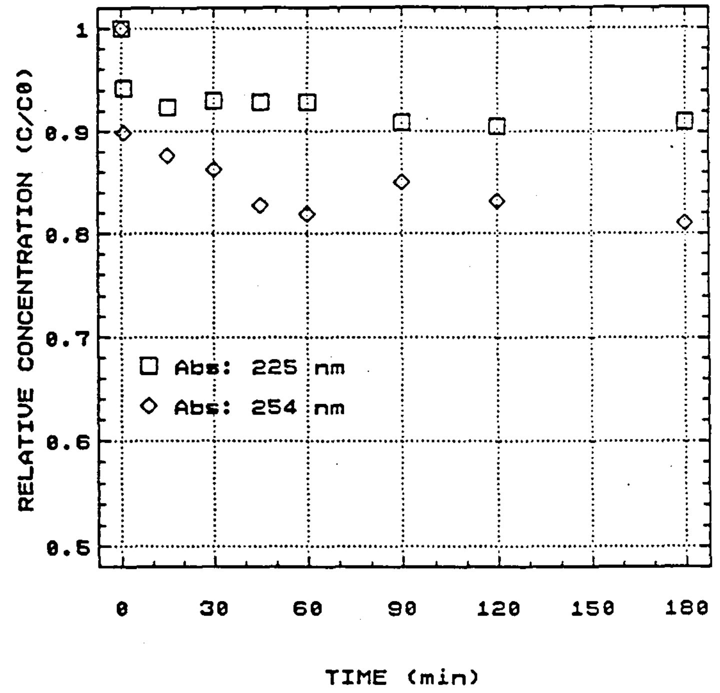


FIGURE 5-5
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
PAC dosage of 40 mg/*l*

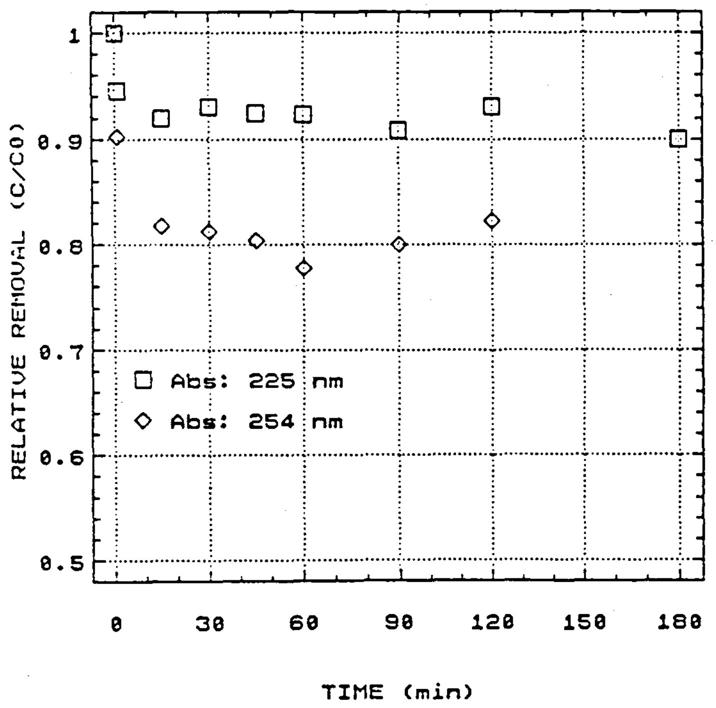


FIGURE 5-6
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
PAC dosage of 60 mg/*l*

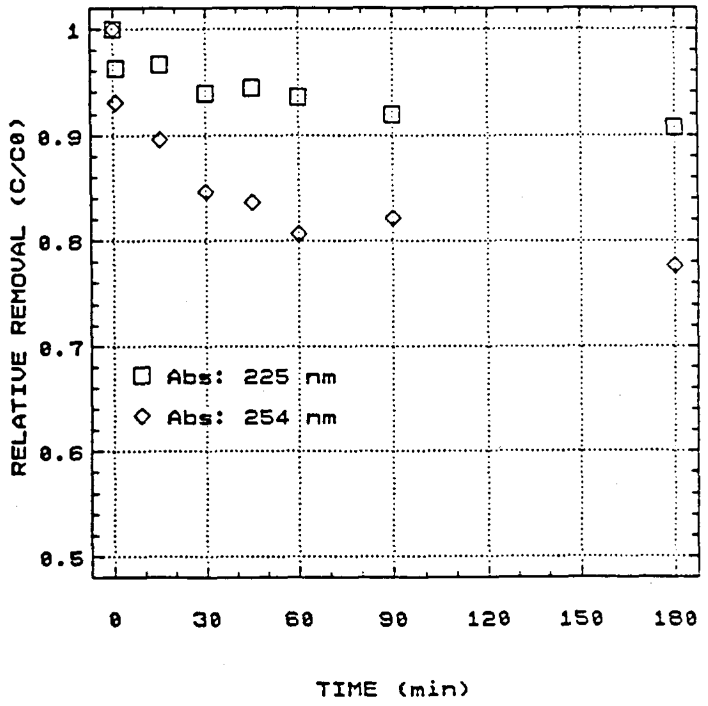


FIGURE 5-7
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
PAC dosage of 100 mg/*l*

concentration measured at 254 nm. Presumably this can be ascribed to the fact that a large number of very diverse dissolved substances absorb light at the lower wavelengths, only some of which are adsorbed onto the PAC. Even at such high dosages as 200 mg/ℓ PAC, only about 30% of the dissolved substances (at 254 nm) were removed. On the basis of these results a PAC dosage of 50 mg/ℓ was selected for the next set of tests. Figures 5-9 and 5-10 are direct graphical comparisons between different dosages measured at the two wavelengths. It is clear that absorption at 225 nm is too insensitive for further use here.

Figure 5-11 summarizes the performance of different powdered activated carbons for the removal of dissolved organic substances measured at a UV wavelength of 254 nm. Details of the specifications of four of the PAC's SA2, SA4 (=SA45)) CAI and CA3 (all manufactured by NORIT and supplied by Holpro Chemical Corporation) are provided in Appendix 2. It appears that none of these PAC's removed more than 20% of the organic loading, but that SA45 and CAI performed better than the other carbons. The former brand is widely used in water treatment, and was consequently selected for further studies.

5.3 Practical operational considerations

Firstly the know-how had to be developed to operate the PACDAF pilot plant. The main pump, as well as the dosing pumps for the powdered activated carbon and the coagulant had to be calibrated. The pilot plant was tested hyrdaulically and care had to be taken that the water level in the pilot plant remained at an equal level at both of the weirs. This was extremely difficult as the pilot plant was erected on soil and with the water entering the system, due to the larger weight, the ground tended to cave in.

Due to the poor removal of dissolved substances, as was shown in Figures 5-9 and 5-10, it was decided to spike the water at Temba with dodecylbenzene sulphonate (DBS), and monitor the removal of DBS through the PACDAF pilot plant. Laboratory tests were done to determine the dosage activated carbon required to remove 30 mg/ℓ of DBS. Poor removal of the DBS was obtained as can be seen in Figure 5-14, with the best results at a very high PAC dosage of 200 mg/ℓ. In spite of the high dosage required, it was decided to do test runs with a PAC dosage of

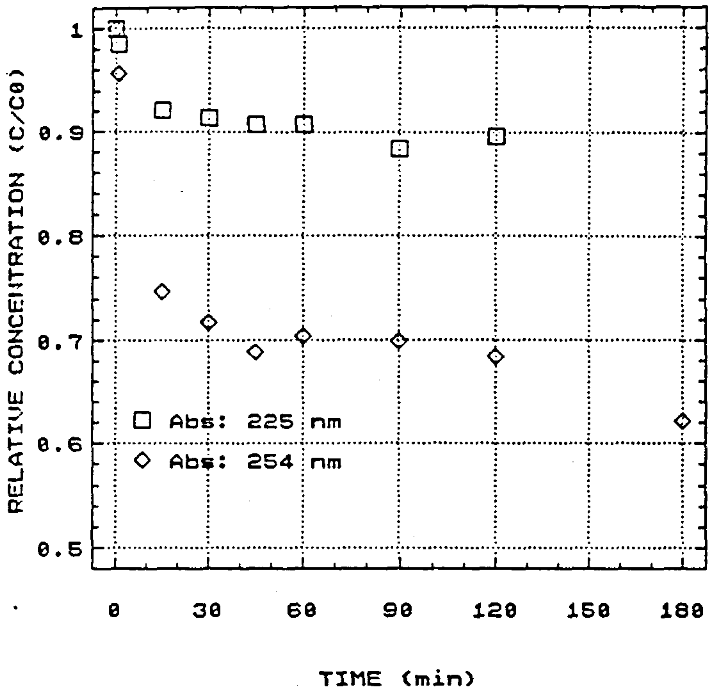


FIGURE 5-8
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
PAC dosage of 200 mg/.

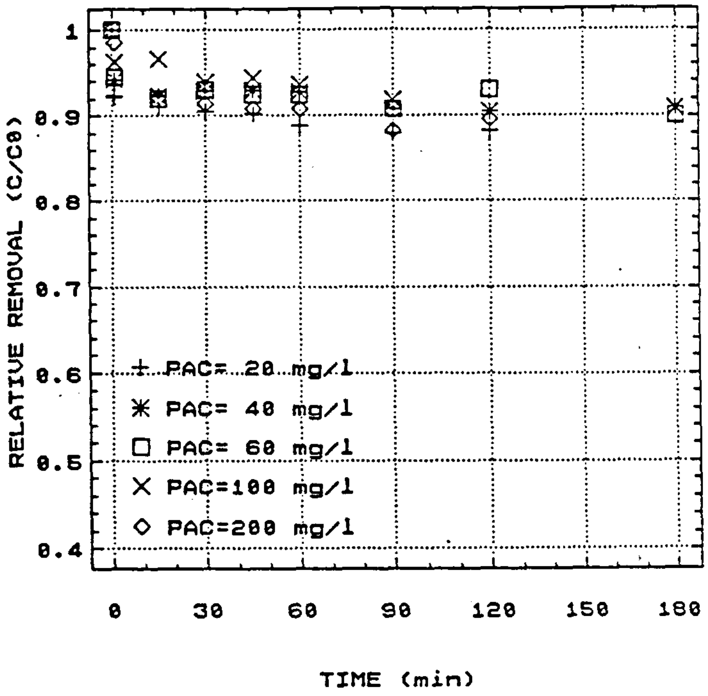


FIGURE 5-9
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
Absorbance at 225 nm

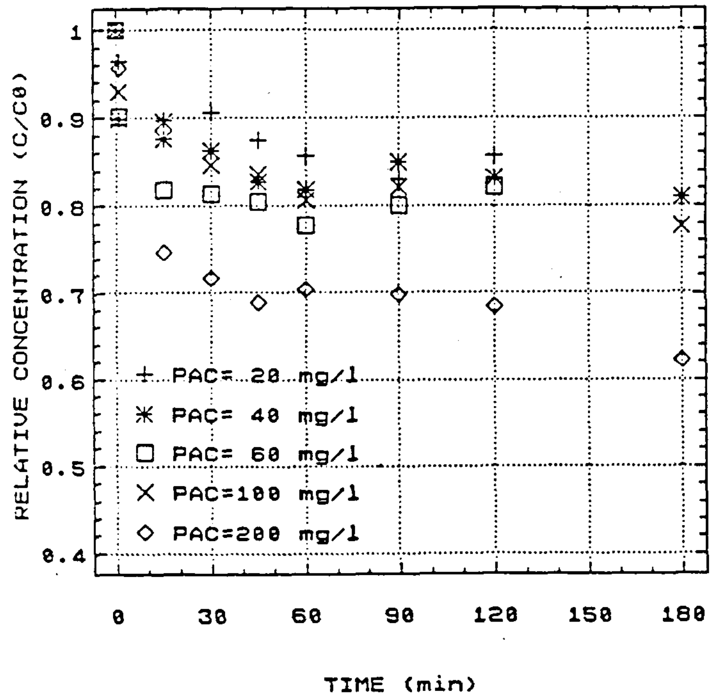


FIGURE 5-10
EFFECT OF GS 48 PAC ON DISSOLVED ORGANICS CONCENTRATION
Absorbance at **254 nm**

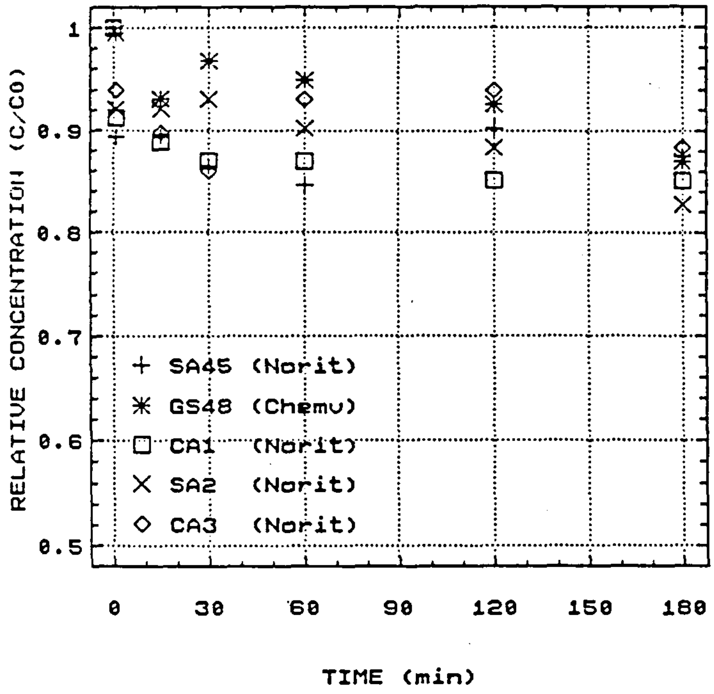


FIGURE 5-11
PERFORMANCE OF DIFFERENT POWDERED CARBONS FOR THE REMOVAL OF DISSOLVED ORGANIC SUBSTANCES (Absorbance at 254 nm)

Figure 5 – 12: The PACDAF pilot plant

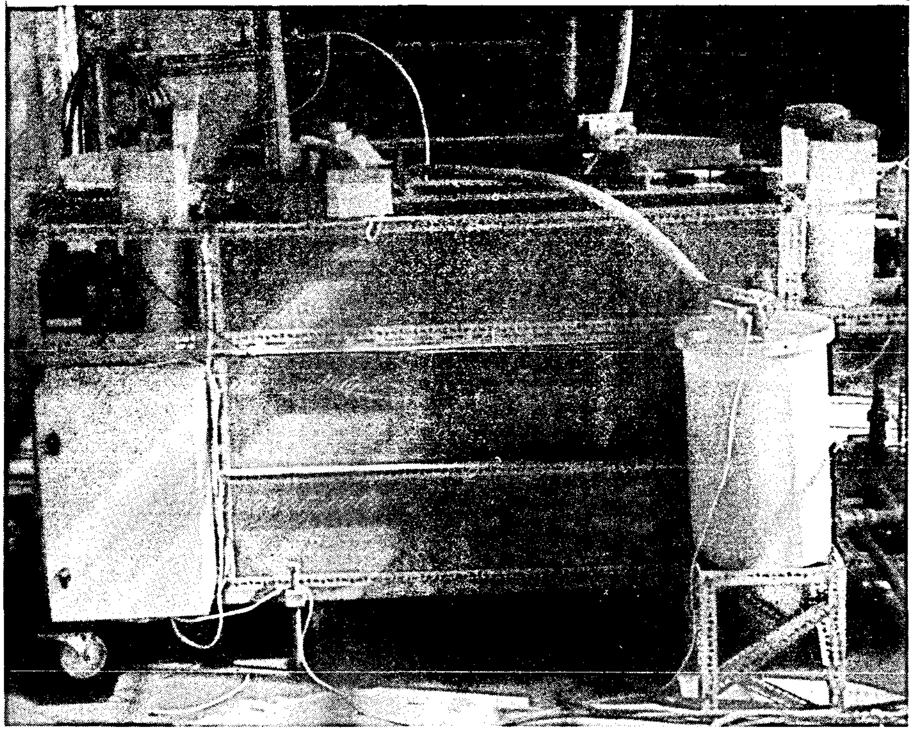
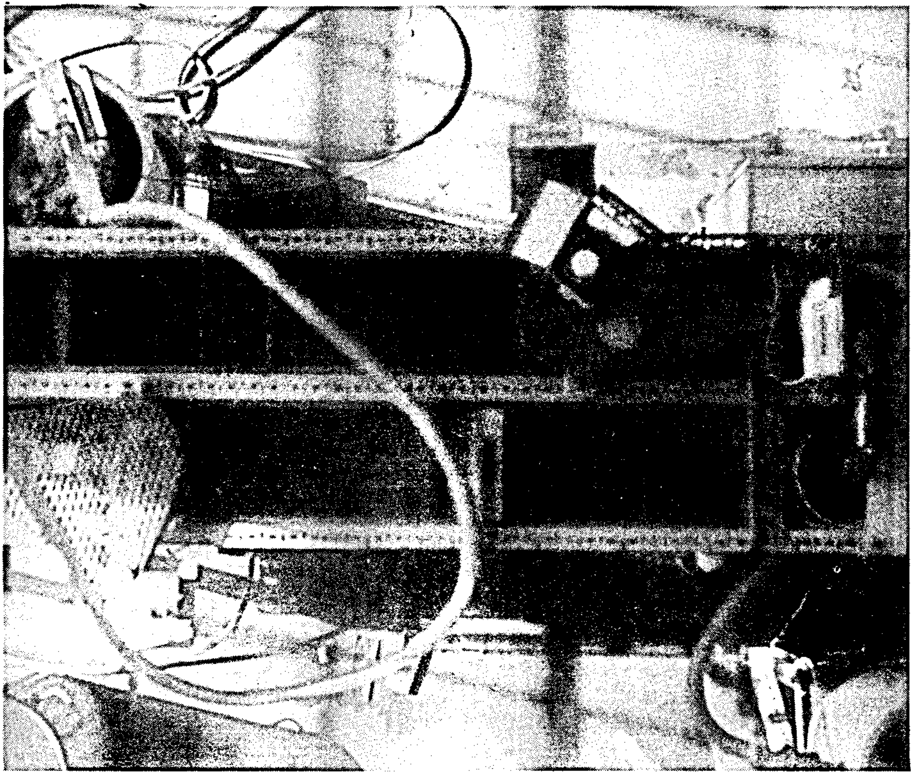


Figure 5 – 13: Top view of the PACDAF pilot plant



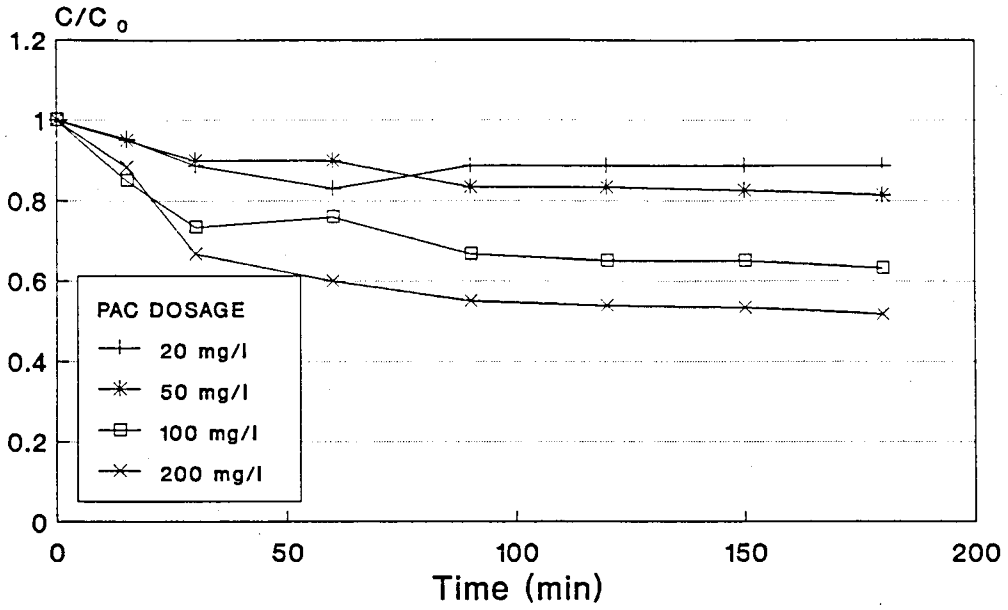


FIGURE 5-14
DBS REMOVAL BY SA-45 PAC
Laboratory tests

100 mg/ℓ (where reasonable removal of DBS took place) to measure the performance of the pilot plant.

However, at this stage difficulties were encountered at Temba water works with their water feed. At irregular intervals, the water works was shut down, sometimes for as long as a week. It was therefore decided to move the PACDAF pilot plant to a process laboratory at the CSIR and to conduct further studies there. Figures 5-12 and 5-13 show the PACDAF pilot plant in the laboratory.

5.4 PACDAF pilot plant experiments

5.4.1 Experimental procedure

The following experimental procedure was followed:

a) A laboratory test was first conducted where the effect of different dosages ferric chloride on DBS concentration were studied. Different dosages $FeCl_3$ were added to a 30 mg/ℓ DBS solution in 500 mℓ containers, stirred, and then the flocs were allowed to settle. The DBS concentration in the upper half of the container was measured, and the results are summarized in Table 5-2.

Table 5-2 : DBS removal by coagulation

Dosage $FeCl_3$ (mg/ℓ)	10	40	60	100
DBS (mg/ℓ) in upper half of container	22,5	22	10,5	2,5

As can be seen, the best coagulation of DBS took place at a $FeCl_3$ dosage of 100 mg/ℓ and consequently all the experiments were conducted with this dosage $FeCl_3$.

b) Feedwater with a DBS concentration of 30 mg/ℓ was prepared.

c) SA 45 activated carbon was grounded to ensure that no particles larger than 50 microns were used.

d) A PAC dosage was prepared so that a carbon dosage of 100 mg/ℓ could be introduced into the pilot plant.

e) A $FeCl_3$ dosage was prepared so that a coagulant dosage of 100 mg/ℓ could be introduced into the pilot plant.

f) The experiment was started when the PACDAF pilot plant had a continuous overflow at both weirs and the dissolved air flotation (DAF) recirculation rate was calibrated at 20 % of the flow through the pilot plant. At this recirculation rate, sufficient flotation of the PAC took place.

5.4.2 Results

Two test runs were conducted. The only difference between the two runs was that no

PAC was recycled with the second run, thus effectively consisting of one DAF unit. This could mean that if one DAF unit proved to be sufficient, i.e. sufficient removal of targetted compounds as well as the powdered activated carbon, the retention time for the pilot plant could be halved as well as the initial capital outlay. Running costs will also be reduced accordingly. The results of the two test runs are summarized in Table 5-3 and graphically in Figures 5-15 to 5-17

Table 5-3 : Results of PACDAF test runs : Quality of product water leaving the pilot plant

Time (min)	Test run 1 : 2 DAF units			Test run 2 : 1 DAF unit		
	Relative concentr. of DBS	DOC (mg/ℓ)	Turbidity NTU	Relative concentr. of DBS	DOC (mg/ℓ)	Turbidity NTU
0	1	15	4.5	1	15	4.5
30	0.963	15	1.8	0.952	13	2.6
60	0.963	13.8	1.7	0.914	13.4	1.0
90	0.881	11.8	1.9	0.876	10.9	2.2
120	0.867	12.9	1.4	0.867	11	2.2
150	0.853	11.7	1.6	0.711	9.7	1.9
180	0.84	10.7	1.5	0.681	8.4	1.8
210	0.831	8.4	1.6	0.670	7.9	1.7
240	0.818	7.4	1.6	0.662	7.6	2.1
290	0.782	6.1	1.6	0.640	7.6	2
300	0.772	6.2	1.8	0.640	7.6	1.8
330	0.762	6.2	1.4	0.640	7.6	1.9

5.4.3 Discussion

The PACDAF pilot plant performed well and the results obtained from the test runs were well in accordance with experimental results that were obtained from tests conducted in the laboratory. The test run that was carried out with one DAF unit reached its equilibrium concentration after 270 minutes. In comparison, the test run carried out with both DAF units did not reach equilibrium by the time when the test run was terminated at 5.5 hours.

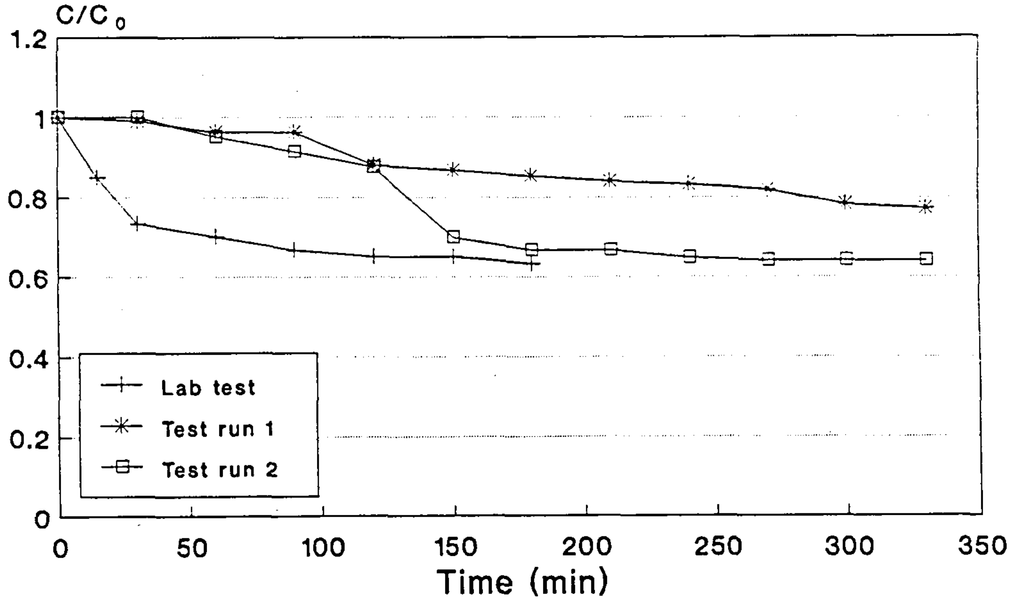


FIGURE 5-15
DBS REMOVAL BY SA-45 PAC
PACDAF pilot plant

The DOC content in the water declined to around 6 mg/ℓ for both test runs which indicates good removal of the activated carbon by the flotation units. It also demonstrates the adsorption efficiency of the carbon.

Turbidity analysis was done on the water outlet of the pilot plant. The final turbidity of the water in the first test run (two DAF units) was 1.5 NTU while the turbidity of the water in the second test run was 1.9 NTU. The difference (which is not significant) between the turbidities is due to the fact that more powdered activated carbon is removed by two DAF units than by one unit. The difference however is minimal and one DAF unit could prove to be sufficient.

6. CONCLUSIONS

- All of the stated objectives for the laboratory scale research on this project relating to the adsorption efficiency and separation of activated carbon were successfully completed.

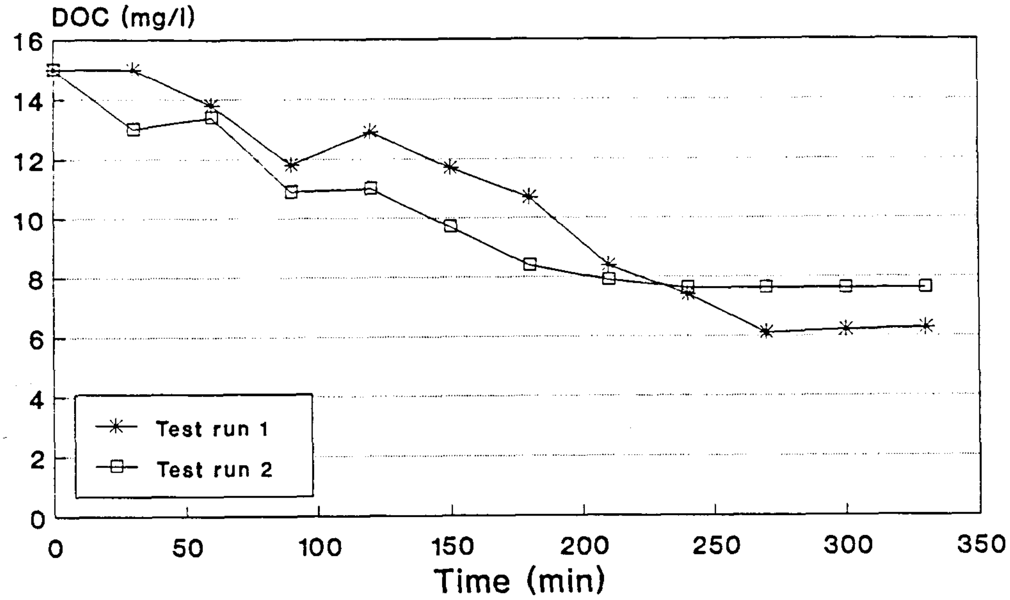


FIGURE 5-16
DOC CONTENT OF PRODUCT WATER
PACDAF pilot plant

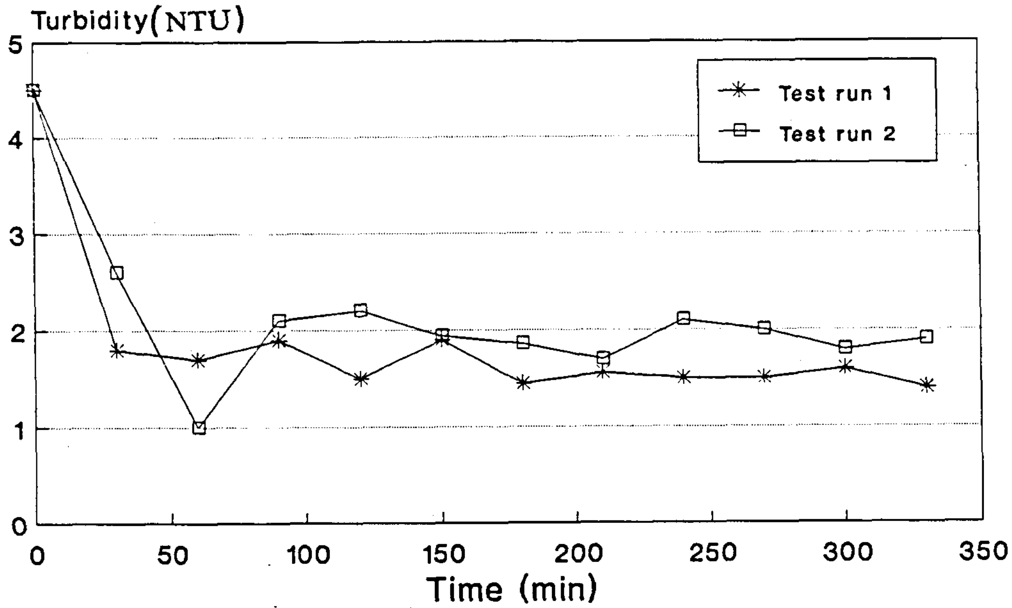


FIGURE 5-17
TURBIDITY OF PRODUCT WATER
PACDAF pilot plant

- Removal of PAC by DAF produced a statistically significant higher removal efficiency than settling.
- The results indicate that powdered activated carbon (PAC) can be efficiently removed by dissolved air flotation (DAF) from residual turbidity levels of around 4.5 down to around 1 NTU.
- Alum and ferric chloride were found to be most efficient as coagulants with dosages of 10 mg/ℓ respectively. Results make it possible to select an appropriate coagulant type and dosage for a given PAC concentration.
- It appears that reflocculation of PAC which has previously been flocculated, is feasible in the DAF process.
- The adsorption capacity of the PAC employed for phenol and dodecylbenzene sulphonate (DBS) is not markedly influenced by the prior coagulation and flocculation thereof with alum and ferric chloride.
- Ferric chloride at concentrations of 30 to 50 mg/ℓ had only a slight effect upon the rate of phenol and DBS adsorption by the 180-250 micron particle size fraction of a typical water application activated carbon.
- The adsorption equilibrium capacity of activated carbon was found to be independent of particle size distribution for the particle size range of 20 - 600 microns studied.
- Particle size distribution had a significant effect on the adsorption rate of the model compounds, phenol and DBS, with the adsorption rate at smaller particle sizes much higher than the adsorption rate at larger particle sizes.
- Turbidity profiles indicated that activated carbon particles below 56 microns settle slowly with some of the powdered carbon remaining in suspension for several hours.
- A particle size fraction of about 75 to 150 microns nominal diameter was determined to have both optimum free settling characteristics and adequate adsorption rate characteristics for use in successive counter-current agitated reactors.
- A two-stage counter-current powdered carbon/dissolved air flotation (PACDAF) mobile pilot plant has been constructed and hydraulically tested.
- The running time of the PACDAF pilot plant should be in the order of 6 hours to be able to correctly analyze the results.
- Removal of the targetted species (Phenol and DBS) as well as the powdered activated carbon were well in accordance with results obtained in small scale laboratory tests
- A method has been established at the University of Pretoria for the analytical determination and quantification of the odour-producing compounds, geosmin and

2-methylisoborneol, commonly associated with high concentrations of certain algal species in eutrophied water sources.

- From the results (Table 5-3) it can be concluded that one DAF unit is sufficient for the treatment of carbon particle suspended water.

7. RECOMMENDATIONS

Laboratory investigations and experimental testwork have indicated that the PACDAF unit should be capable of succesfull removal of both dissolved organic compounds and suspended impurities, such as algae, from eutrophic water sources.

In light of the results obtained during the test runs and the addisional capital and running costs that will be necessary to implement a double-reactor, double DAF system, it is not advisable to use a two stage DAF unit where one DAF unit has prooved to be sufficient such as the full scale plant at Schoemansville on the banks of the Hartbeespoort Dam.

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APPENDIX 1

REPORT ON THE ANALYSIS OF TASTE AND ODOUR COMPOUNDS

Institute for Chromatography
University of Pretoria

Gas Chromatographic/Mass Spectrometric

determination of

GEOSMIN and METHYLISOBORNEOL

in

Water Samples

INTRODUCTION

Many of the complaints received by water utilities are associated with objectionable tastes and odors in drinking water. These problems are usually difficult to control and very often the concentrations of the compounds causing these taste and odor problems are at exceptionally low concentrations (low ng/ℓ). Tastes and odors have been traced to industrial effluents, however, natural causes due to microbiological activity have been a widespread cause of these problems. A common taste and odor described as a woody or potato-bin, flavour has been attributed to the compound Geosmin. This compound has been isolated from actinomycetes cultures and has also been shown to be a metabolic product of various blue-green algae. Another compound producing a musty camphorous flavour is 2-methylisoborneol, also produced by actinomycetes.

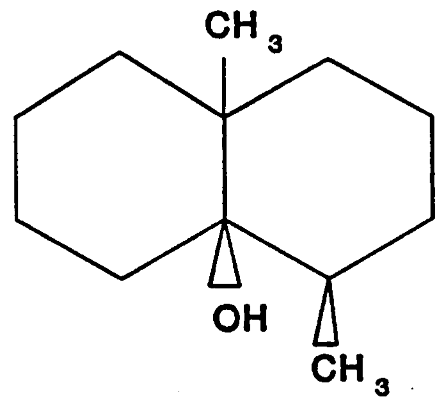

Figure 1 : Geosmin Molecular Structure

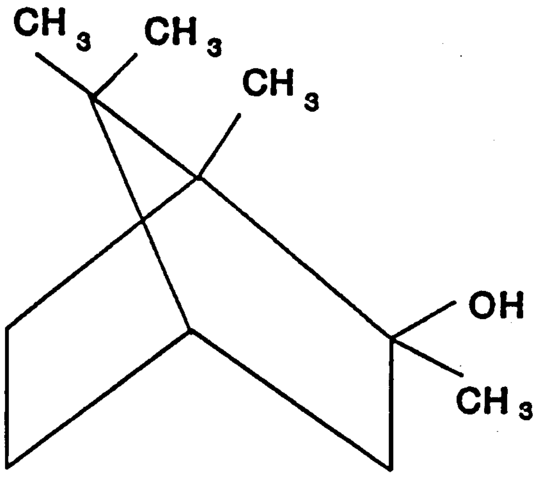

Figure 2 : MIB Molecular Structure

Both Geosmin and 2-methylisoborneol are saturated tertiary alcohols (Fig 1 & 2) and are thus resistant to oxidation by the normal disinfectants used in water purification processes such as chlorine, chlorine dioxide and ozone. It is therefore difficult to remove the compounds from water using conventional purification processes, especially when they occur in the low ng/ℓ concentration range.

The analytical methods available for the determination of these odorous compounds included sensory evaluation by the human nose and gas chromatographic techniques. The human nose has been found to be the most sensitive detector available but it is unable to discriminate specific odors in the presence of stronger ones and it rapidly suffers from fatigue. Gas Chromatography (GC) with flame ionization detection and mass spectrometry (MS) have for a long time been accepted as the best instrumental methods available. The application of these instruments has been limited because of the unavailability of suitable methods of concentration to provide the necessary sensitivities.

The development of the Closed-Loop Stripping Analysis (CLSA) technique by Grob in 1972 has combined a high concentration factor with a small sample size and a relatively short processing time, for raw and finished waters. The successful application of this method, by Krasner, Hwang, and Mcuire (1981), for the analysis of organoleptic compounds has resulted in it being accepted by Standard Methods.

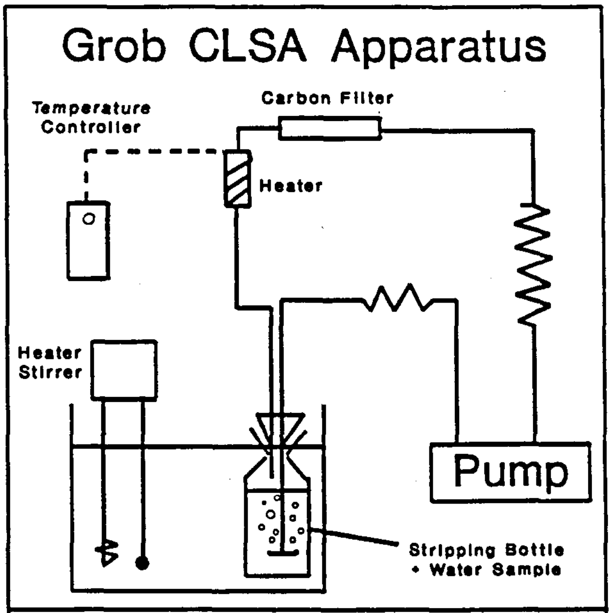

Figure 3: Closed-loop Stripping Apparatus

Analytical method

Stripping Apparatus

The apparatus required to purge the organic compounds from the water sample (Fig 3) consisted of a one litre glass stripping bottle with approximately 200 mℓ headspace in which the sample was placed. The stripping bottle was placed in a water bath so as to accurately regulate the temperature of the sample. All standards and samples were stripped at the same temperature.

A heater was placed in the connecting tubing to the filter holder, close to and just in front of the holder to maintain the temperature about 20-25 °C above the temperature of the water bath. This prevents water vapor condensing on the carbon filter which would lead to a loss in the recovery of the organic compounds.

The filter holder is made of stainless steel and especially manufactured to reduce the dead-volume area. The carbon filter (Fig 4) is made of glass and contains 1.5 mg of activated carbon.

The circulating pump, with bellows of stainless steel, has a pumping rate of about 1-1.5 litre/min. The flow rate through the system varied, being dependant on the filter resistance to the air flow. All connections were made either of stainless steel or polytetrafluoroethylene (PTFE) to prevent contamination occurring.

The apparatus used to extract the organic compounds absorbed onto the carbon (Fig 4), consisted of 50 μℓ capacity glass vials which could be attached to the carbon filter with shrink PTFE tubing. These vials were made from narrow bore glass tubing.

Stripping Procedure

The sample was shaken and the stripping bottle rinsed with the sample and then filled to the 1 litre mark. Anhydrous Sodium Sulphate (baked in an oven at 400 °C overnight) was then added to the water sample to increase the ionic strength. Fifty micrograms (50 μg) of l-Chloromethylheptane was then added, as internal standard. The stripping bottle was then immersed in the water bath, at 25 °C, to just below the stopper and connected to the system. With the in- line heater at 45 °C an auxiliary carbon filter was put into the filter holder and the system prestripped for 1Os. The auxiliary filter was then replaced with a clean filter and the sample stripped for 2 hours. The temperature of the water bath was slowly increased during this period to 50 °C to improve the recoveries.

Extraction of Filter

The carbon filter was removed from the filter holder to extract the adsorbed compounds from the carbon bed. The filter was fitted to the extraction vial, containing 2 µℓ carbon disulphide (CS_2), by means of a piece of PTFE tubing, so as to leave no dead-space between the glass parts (Fig 4).

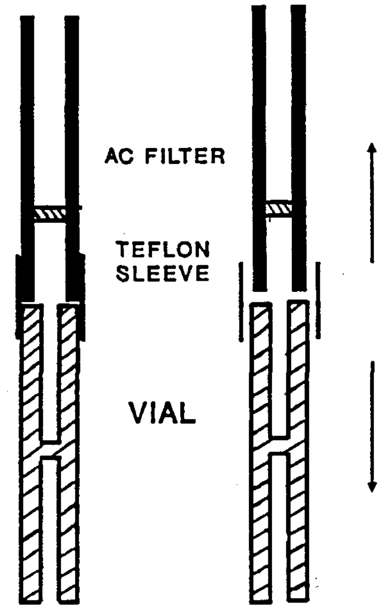

Figure 4: Carbon Filter & Extraction Vial

With a clean syringe, 1O μℓ of CS, was added to the filter above the carbon. The extraction vial was warmed with the hand and the CS2 was pulled and pushed alternately back and forth through the carbon filter, extracting the absorbed organic compounds. This process was repeated 10 times. With the vial and filter tightly butted the vial was cooled thereby drawing the CS, into the vial. With a gentle swing or shake, the transfer of the CS, to the vial, was completed. The carbon was extracted again with a further IO μℓ and then 5 μℓ of CS_2. The GC/MS analysis of the extract was done immediately.

Separation and Identification

The separation of the compounds extracted was done by gas chromatography (GC) and the identification by mass spectrometry (MS).

GC/MS Conditions:

Column : 25 mm x 0.25 mm ID OVIOI glass capillary with fused silica'legs'
Carrier Gas : Helium (linear velocity 30 cm/sec) Column Temperature : Initial 40 °C for 2 min to 200 °C @ 8 °C Programme per min to 280 °C @ 20 °C per min
Injector Temp : 230 °C
Interface Temp : 280 °C
Source Temp : 220 °C
Scan Mode : SIM

The introduction of the sample into the GC was done using the so called 'hot-needle' injection technique to reduce discrimination against the high-boiling compounds. The split of the GC injector was closed and 5 μℓ of the sample was injected into the inlet. After 30 s the split valve was opened to purge the inlet.

The MS was run in the single ion monitoring (SIM) mode and the ions used were selected from the mass spectra of the compounds (see figures 5 and 6). The following ions were selected for the detection of the compounds:

2-methylisoborneol : 41,95,107,108,109,135,150,168

Geosmin : 43,55,112,125,126,182

These ions were selected as being the most diagnostic for each compound. To positively identify a compound it was necessary that each set of characteristic ions all maximize at the same retention time and that the relative intensities of these ions match those of the mass spectrum of the compound. It was therefore necessary to obtain spectra of the standards under the same analytical conditions as applied to the samples. A further requirement for a positive identification was that the retention times relative to the internal standard were the same as for the standards run under identical conditions.

Results and Discussion

Standards of Geosmin and MIB, in a 70% ethanol/water solution, at concentration levels of 200 µg/mℓ, were obtained. The standard solutions were submitted for mass spectrometric analysis to obtain the mass spectra of these two compounds (Figures 5 and 6)

To determine the gas chromatographic retention times of these compounds a mixture of both standards with the internal standard was chromatographed, using a flame ionization detector.

The efficiency of the CLSA procedure was then determined by stripping 1 litre of organic-free water, spiked with 50 µg of each standard and the internal standard and analyzing the extract. By using the SIM mode for the determinations, much of the background interference obtained from the sample and the solvent was eliminated. A number of determinations of the standard mixture in organic-free water, were performed to optimize the conditions for stripping the samples. A typical ion chromatogram of the standard mix is included as Figure 7.

The names of the samples analysed are listed in Table 1, with an indication of whether the above mentioned compounds were detected and if so, a rough estimate of the concentration level.

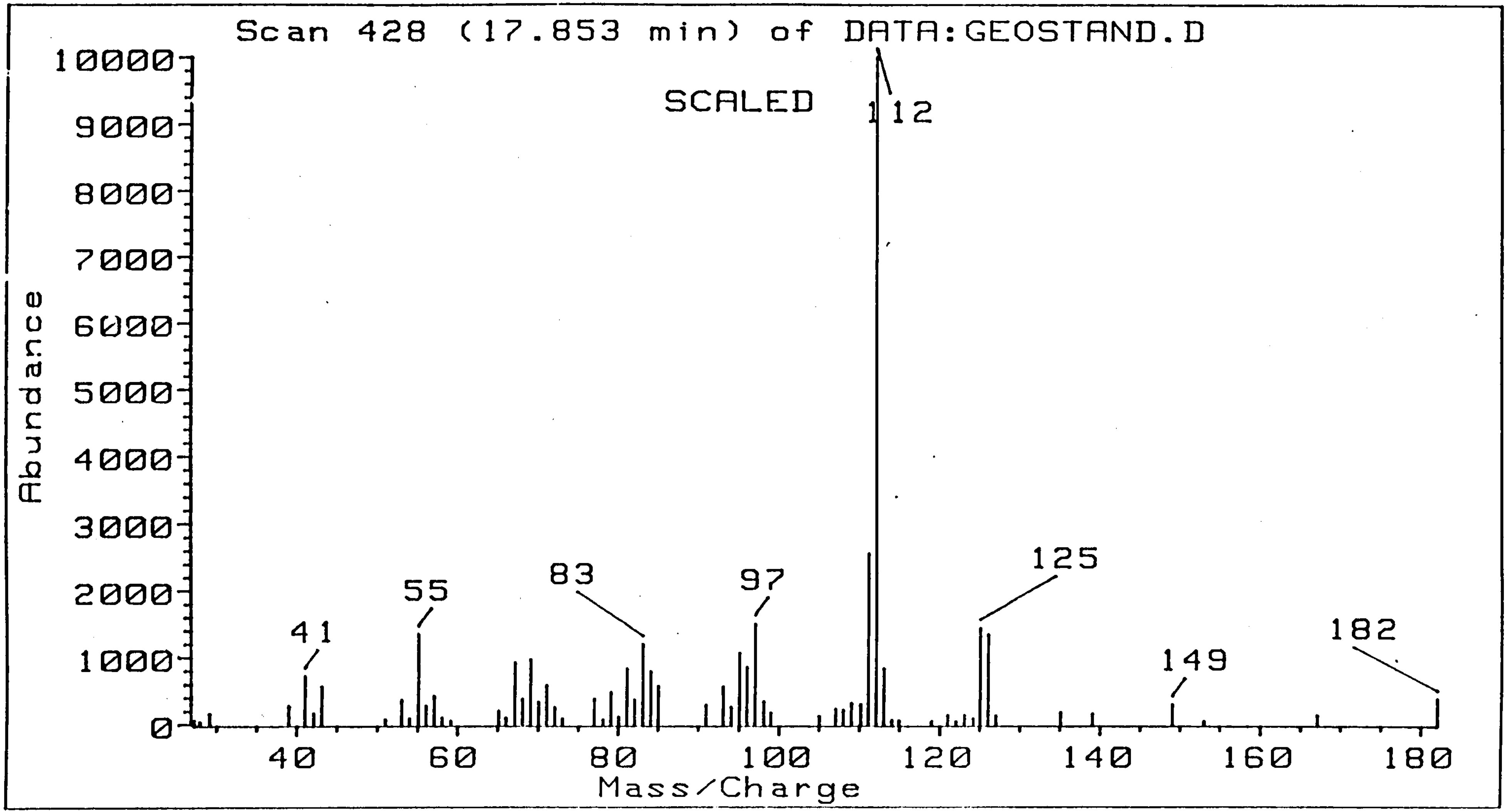

Figure 5 : Mass Spectrum of Geosmin

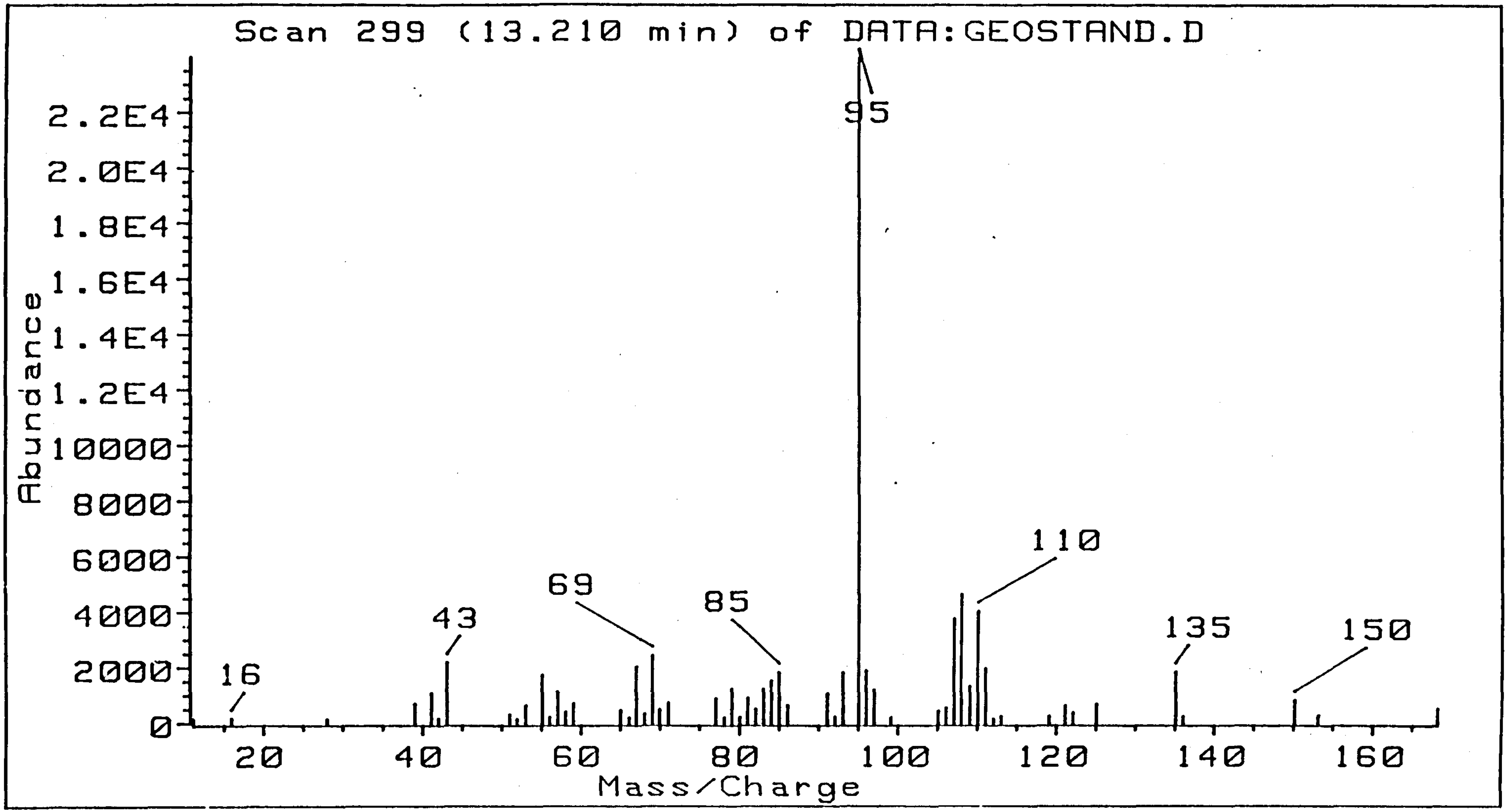

Figure 6 : Mass Spectrum of Methylisoborneol (MIB)

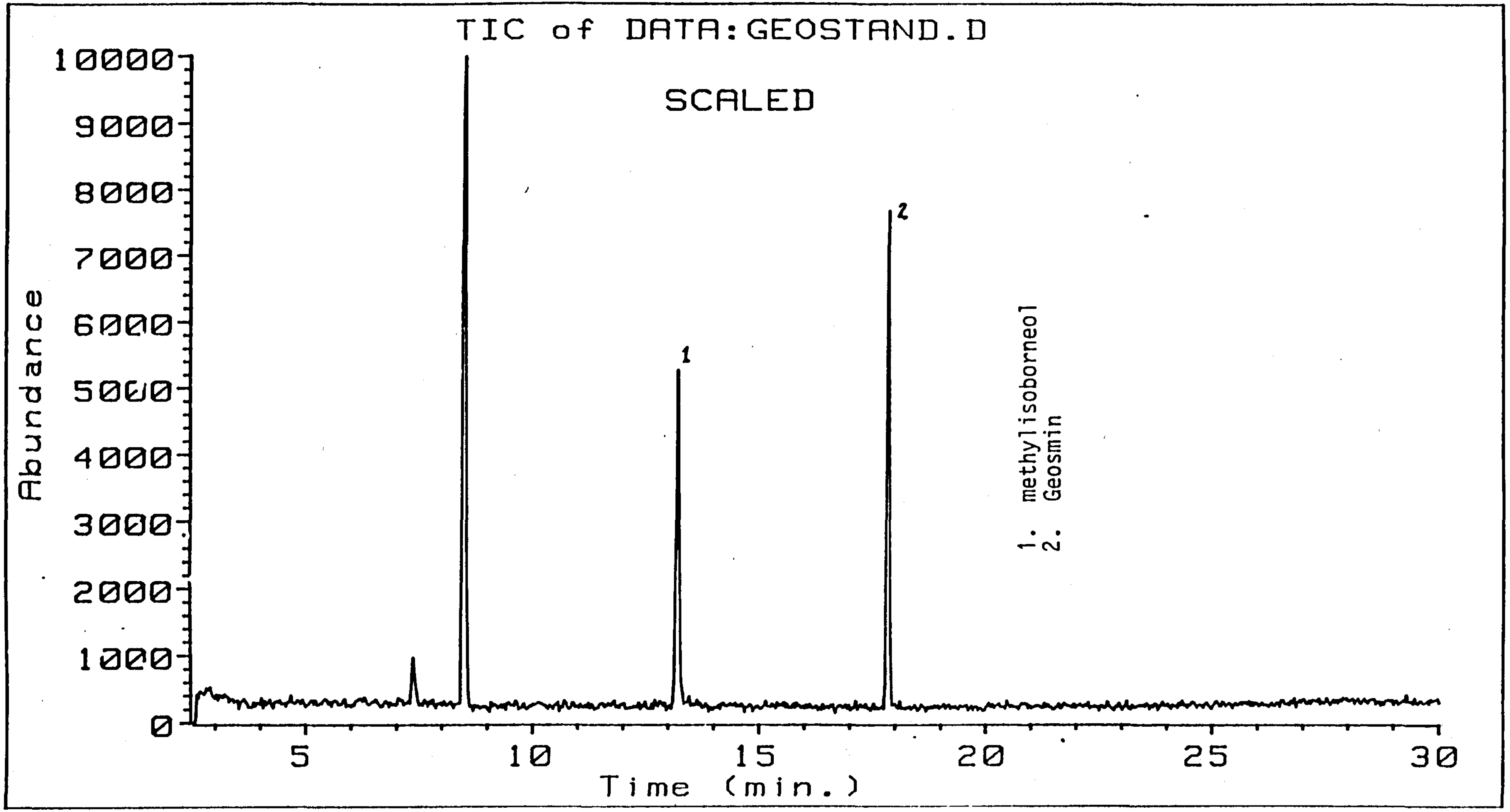

Figure 7 : Ion Chromatogram of the Standards

Table 1. Samples Analysed.

Sample Name	Geosmin	MIB	Conc.
Skoonspruit		ND	
Roodeplaat Dam	ND	ND	
Schoonspruit	ND	ND	
De Kroon Dam	ND	ND	
Vaal Dam	D	ND	8 µg/ℓ
Standerton	ND	ND	
Tweelingpan	D	ND	70 µg/ℓ
Roodeplaat	ND	ND	

ND - Not detected

Geosmin was detected in only two of the samples submitted (Table 1). MIB was not detected in any of the samples. The ion chromatograms of the two samples in which Geosmin was detected are shown in figures 8 and 9. The Geosmin peak in the Tweelingpan sample can be clearly seen, at the same retention time as in the standard chromatogram. The effectiveness of this method in isolating organic contami-nants from a water matrix has been demonstrated by various authors, in particular, compounds which are non-polar in nature and or low solubility. The high solubility of Geosmin in water does reduce the percentage recovery of this compound from a water matrix.

Difficulties encountered with the method are mainly due to the fouling of the carbon filters. This can affect the price of the analysis because of the high cost of replacing the carbon filters. The degree of total contamination of the samples directly affects the lifetime of the carbon filter regardless of the various cleaning techniques that are used to clean the filters. Heavy sample contamination rapidly blocks the carbon filter. This method is thus not suited for continued analysis of excessively contaminated waters such as effluents from sewage works or industry. In general, the Grob Closed-Loop Stripping Analysis technique was adapted mainly for the extraction of contaminants from finished waters.

The analysis of very low concentrations of Geosmin and MIB in water is limited because of the volume of carbon disulphide required (20 µl) to extract them from the carbon filter. This volume of solvent cannot be injected directly into a GC under normal conditions (usually <= 5 μℓ), thus only a portion of the extract is analysed thereby reducing the sensitivity. Because of the volatility of the compounds, concentration of the extract by evaporation will result in a partial loss of the extracted compounds.

The Dynamic Solvent Effect technique, developed by the Institute for Chromatography at Pretoria University, may be an alternative method for the extraction, concentration and analysis of these compounds. The method was originally developed for the analysis of essential oils and fragrances. It will therefore be necessary to research and develop the method to meet the requirements necessary for the isolation and analysis of organoleptic substances. Indications are that a smaller sample volume will be required (50-100 ml) which would simplify the sample handling procedures.

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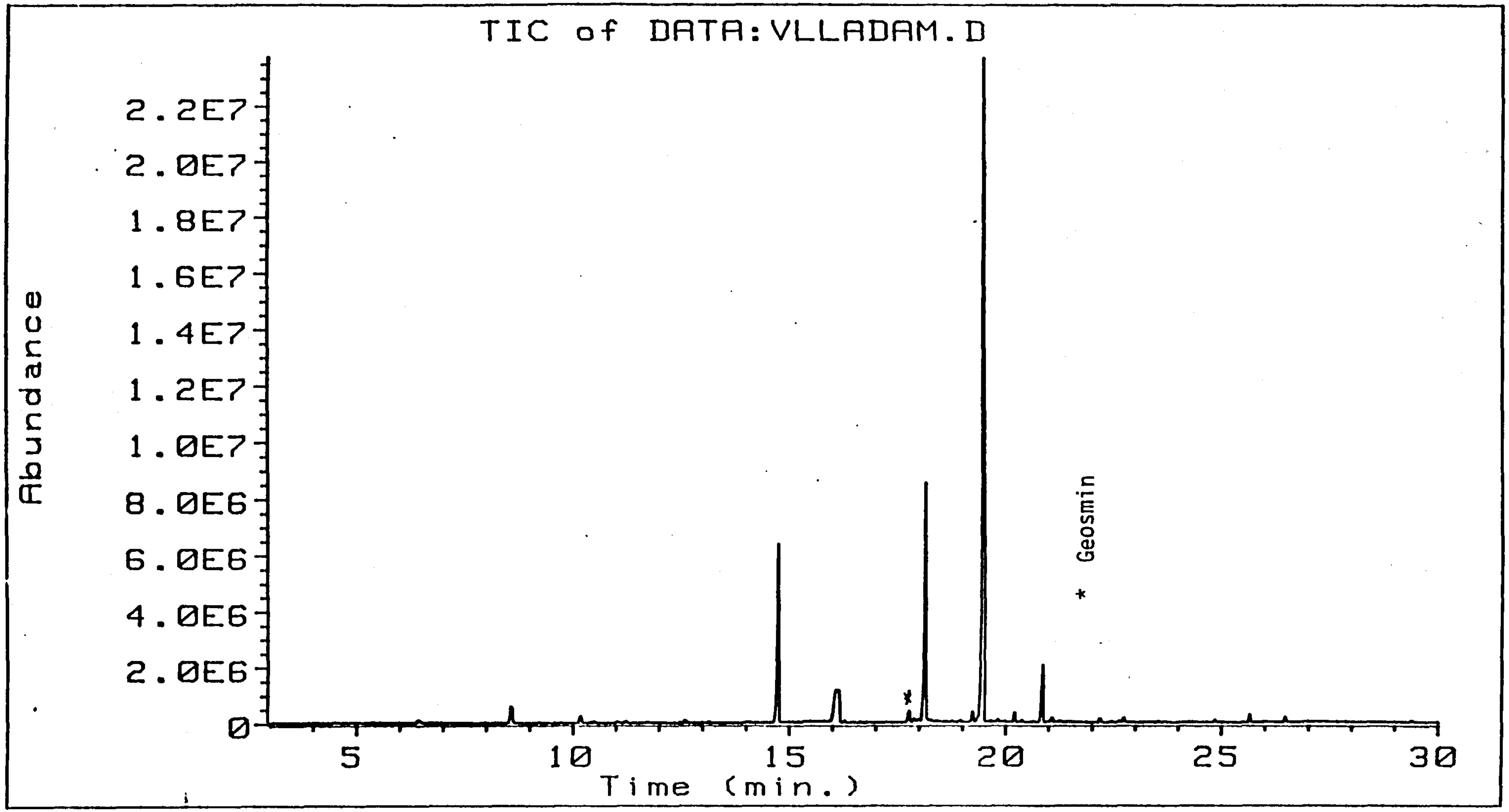


Figure 8 : Selected Ion Chromatogram of Vaaldam Sample

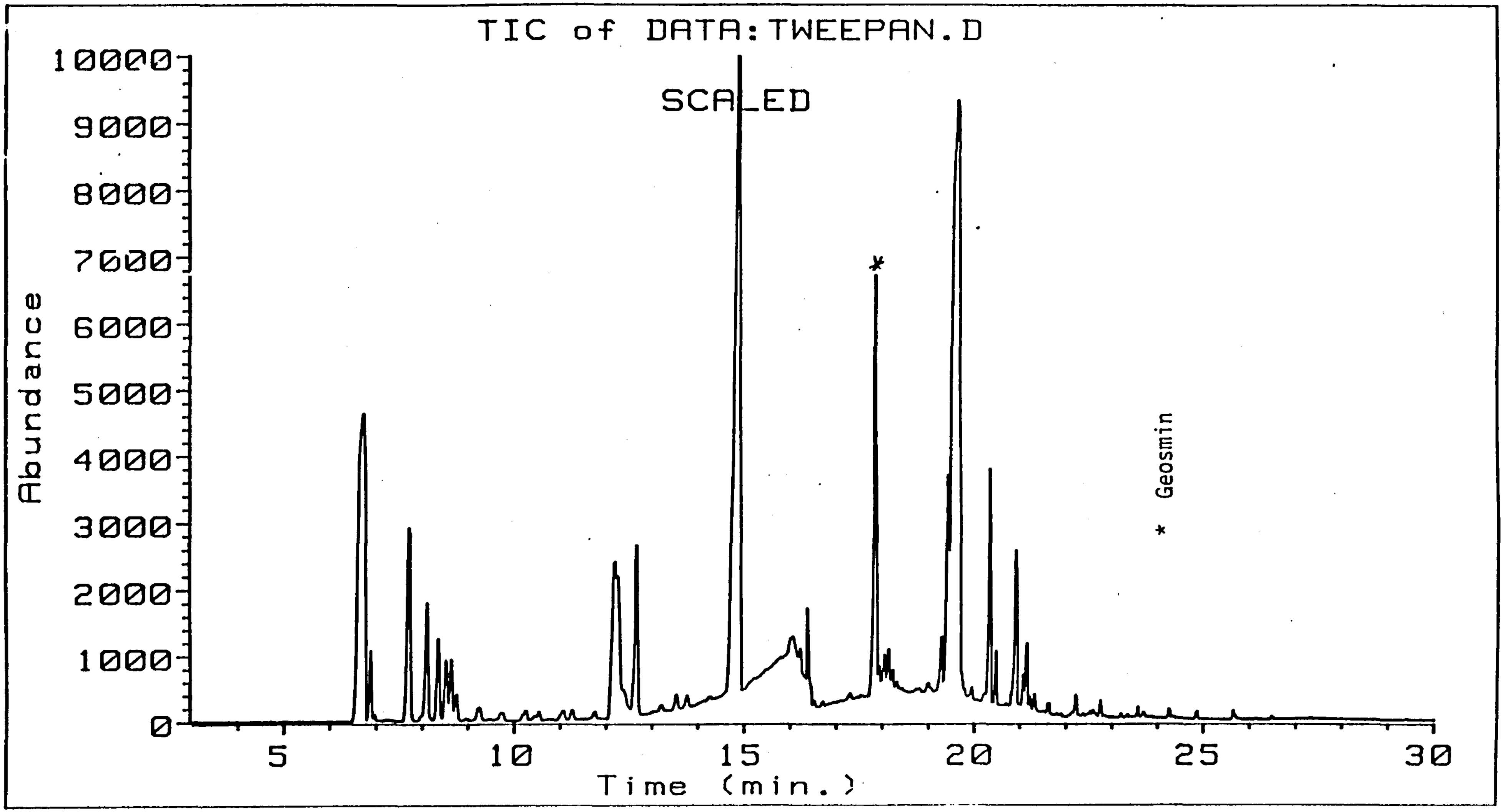


Figure 9 : Selected Ion Chromatogram of Tweeling Dam Sample

DATASHEET

NORIT SA 2

POWDERED ACTIVATED CARBON

NORIT SA 2 is a steam activated carbon with a high adsorptive capacity that can be used in a large range of applications. It removes dissolved organic material of both low and high molecular weight.

NORIT SA 2 is especially suitable for decolourization and purification of:

- heavily polluted water.
- lactose.
- plasticizers (di-alkylphtalates).
- inorganic acids and salts.
- alkaline electroplating baths.

TYPICAL ANALYSIS			METHOD OF ANALYSIS
Apparent density	g/l	410	DIN 53194
Moisture (as packed)	%	2	ASTM 2867-70
Ash content	%	7	ASTM 3866-70
Phenol adsorption	%	4.5	DIN 19603
Molasses number		350	NORIT Method
Methylene blue adsorption	%	14	NORIT Method
Iodine number	mg/g	850	AWWA B 604-74
Internal surface (B.E.T.)	m^2/g	800	
pH		alkaline	NORIT Method
Particle size			
> 10 micron	%	77	wet sieving
> 44 micron	%	36	
> 74 micron	%	18	
> 150 micron	%	4	

NOTES

- Typical analyses are the average analysis figures based on the last two years of production.
- NORIT SA 2 meets the requirements of the U.S. Food Chemicals Codex (3rd. ed., 1981).
- This Datasheet replaces previous issues.

PACKING

NORIT SA 2 is supplied in valve sealed paper bags and can be delivered either separately, in box pallets or on pallets with shrinkwrapping. Netweight per bag 20 kg. Netweight per pallet 960 kg.

On request NORIT SA 2 can also be supplied in bulk.

DATASHEET

NORIT SA 4

POWDERED ACTIVATED CARBON

NORIT SA 4 is a steam activated carbon that can be used in a large range of purification applications.

NORIT SA 4 is especially suitable for potable water treatment, for decolourization and purification of vegetable oils and fats, inorganic acids and salts, organic acids, alkaline electroplating baths etc., and for improvement of smell and taste of beverages, e.g. wine, fruit juices.

TYPICAL ANALYSIS			METHOD OF ANALYSIS
Apparent density	(g/l)	490	DIN 53194
Moisture (as packed)	(%)	2	ASTM 2867-70
Ash content	(%)	6	ASTM 2866-70
Phenol adsorption	(%)	4	DIN 19603
Molasses number		525	NORIT Method
Methylene blue adsorption	(%)	11	NORIT Method
Iodine number	(mg/g)	750	AWWA B 604-74
Internal Surface (B.E.T.)	(m^2/g)	650	
pH		alkaline	NORIT Method
Particle size:			
> 10 micron	(%)	80	wet sieving
> 44 micron	(%)	37	
> 74 micron	(%)	20	
> 150 micron	(%)	5	

NOTES

- Typical analyses are the average analysis figures based on the last two years of production.
- NORIT SA 4 meets the requirements of the U.S. Food Chemicals Codex (3rd ed., 1981).
- This Datasheet replaces previous issues.

PACKING

NORIT SA 4 is supplied in valve sealed paper bags and can be delivered either separately, in boxpallets or on pallets with shrinkwrapping. Netweight per bag 20 kg. Netweight per pallet 960 kg.

On request NORIT SA 4 can also be supplied in bulk.

DATASHEET

NORIT CA 1

POWDERED ACTIVATED CARBON

NORIT CA 1 is a chemically activated carbon manufactured by the phosphoric acid process. This carbon combines a very high adsorptive capacity with excellent filtration characteristics.

NORIT CA 1 is especially suitable for:
- purification and decolourization of pharmaceuticals and fine chemicals.
- decolourization of hydrolyzed vegetable proteins (HVP), monosodium glutamate (M.S.G.), organic acids, phosphoric acid and salts (STPP).
- wine decolourization.

SPECIFICATION

Moisture (as packed)	%	max. 12	Phosphate (PO_4)	%	max. 3
Methylene blue adsorption	g/100 g	min. 25	Iron (Fe)	ppm	max. 200
pH range		2-3			

TYPICAL ANALYSIS

Molasses number		175	Ash content	%	4
Bulk density (tamped)	g/l	300	Acid soluble material	%	4
Internal surface (B.E.T.)	m^2/g	1400	Iron (Fe)	ppm	100
Particle size:			Calcium (Ca)	ppm	150
> 75 micron (mesh 200)	%	10-20			

NOTES

- Typical analyses are the average analysis figures based on the last two years of production.
- All data using NORIT TESTING METHODS.
- Phosphate, Iron and Calcium are measured in HCl-extract.
- NORIT CA 1 meets the requirements of the U.S. Food Chemicals Codex (3rd ed., 1981).
- This datasheet replaces previous issues.

PACKING

NORIT CA 1 is supplied in valve sealed multiply paper bags, with a polythene outer shrinkwrap, containing 15 kg. 44 bags are supplied, stretchwrapped on a pallet 1100 x 1100 x 2000 mm.

Packing in 10, 5 and 2½ kg bags (dispersable) is also possible - details will be given on request.

NORIT

DATASHEET

NORIT CA 3

POWDERED ACTIVATED CARBON

NORIT CA 3 is a chemically activated carbon manufactured by the phosphoric acid process. This carbon combines a high adsorptive capacity with excellent filtration characteristics.

NORIT CA 3 is especially suitable for purification and decolourization of pharmaceuticals and fine chemicals, organic acids, phosphoric acid and salts, glycerin and food products.

SPECIFICATION

Moisture (as packed)	%	max. 12	Phosphate (PO_4)	%	max. 3
Methylene blue adsorption	g/100 g	min. 20	Iron (Fe)	ppm	max. 600
pH range		2-3			

TYPICAL ANALYSIS

Molasses number		250	Ash content	%	4
Bulk density (tamped)	g/l	360	Acid soluble material	%	4
Internal surface (B.E.T.)	m^2/g	1000	Iron (Fe)	ppm	400
Particle size:			Calcium (Ca)	ppm	250
> 75 micron (mesh 200)	%	10-20			

NOTES

- Typical analyses are the average analysis figures based on the last two years of production.
- All data using NORIT TESTING METHODS.
- Phosphate, Iron and Calcium are measured in HCl-extract.
- NORIT CA 3 meets the requirements of the U.S. Food Chemicals Codex (3rd ed., 1981).
- This datasheet replaces previous issues.

PACKING

NORIT CA 3 is supplied in valve sealed multiply paper bags, with a polythene outer shrinkwrap, containing 20 kg. 40 bags are supplied, stretchwrapped on a pallet 1100 x 1100 x 2000 mm.

Packing in 12½, 5 and 2½ kg bags (dispersable) is also possible - details will be given on request.

NORIT
ACTIVATED CARBON

rinted in the Netherlands

CSIR

DIVISION OF WATER TECHNOLOGY

PACDAF
OPERATION MANUAL

by

M.J.A. VENNEKENS

Pretoria
October 1989

1. PRECAUTIONS

1.1 **NEVER** remove chain guards when stirrers are working.

1.2 To connect the PACDAF-pilot plant to the power source, first ensure that the main switch in the electrical switch box as well as all the other switches are switched off and then connect the PACDAF to the main power supply.

1.3 Before disconnecting the main power supply first switch off all equipment as well as the mian switch in the electrical switch box. Only then can the main power supply be disconnected.

2. SET-UP OF PACDAF

2.1 Always set-up the PACDAF-pilot plant on firm ground. When working on sand metal plates must be put under the 4 adjustment screws and if possible also under the 4 wheels.

2.2 When the PACDAF stands on the required spot, put the unit level using the 4 adjustment screws and a spirit level. The 4 adjustment screws are located at the bottom of the unit. Always avoid to lift the unit from its wheels. This will decrease stability and make operation unsafe.

2.3 Connect the contact tank with stirrer No. 6 (tank A) to the feed pump and place the contact tank under the sludge discharge outlet closest to the pump.

2.4 Connect the other contact tank (stirrer No.5, tank B) at the other side of the unit. The connection in the middle goes to the rapid mix tank, while the connection at the bottom of tank B is connected to the DAF-cell. Raise the contact tank until the top is approximately level with the top of the DAF-cell.

2.5 Connect the stirrers of the contact tanks to the power points in the switch box.

2.6 Connect the dosing pump for PAC to tank B.

2.7 Ensure that all valve seats and O-rings in the connectors are present.

2.8 Connect the unit to the main power suply as described in 1.2.

2.9 Put the chemicals of appropriate strenght in the chemical storage tanks.

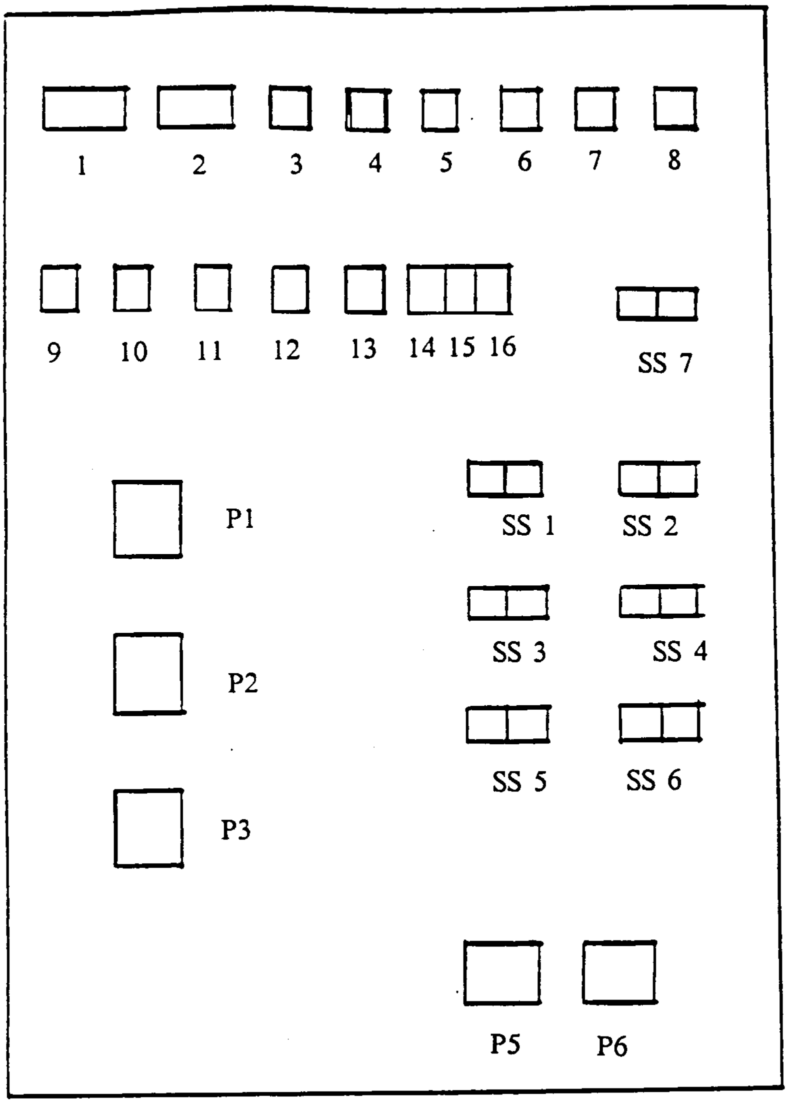
2.10 Install the sludge collection tank under the sludge outlet close to tank B.

2.11 Connect feed water to tank A.

2.12 Install both nozzles in the flotation cells. First insert the rubber stopper and then the nozzles.

3. ELECTRICAL SWITCH BOX

Figure 1 shows the schematic lay-out of the switch box. All stirrers as well as the main feed pump have stop/start switches and all equipment has overload protection switches.



1 main switch
2 feed pump
3 PAC pump
4 coagulant 2 pump
5 poly 1 pump
6 coagulant 1 pump
7 poly 2 pump
8 stirrer 6
9 stirrer 1
10 stirrer 2
11 stirrer 3
12 stirrer 4
13 stirrer 5
14, 15, 16 plugs P1, P2, P3

P1, P2, P3 plugs
P5 plug for stirrer 5 (tank B)
P6 plug for stirrer 6 (tank A)

SS 1 start stop stirrer 1
SS 2 " " " 2
SS 3 " " " 3
SS 4 " " " 4
SS 5 " " " 5
SS 6 " " " 6
SS 7 " " feed pump

FIGURE 1: Lay-out of electrical switch box

4. START-UP OF PACDAF

4.1 The quickest way to start up the PACDAF-pilot plant is to first fill the DAF-cells with clean water by means of a hose pipe and then open valves 3, 4, 5, 6 and 7 (see Figure 2).

4.2 Ensure tank A is full before starting the PACDAF unit.

4.3 Open valve 1 and bleed the feed pump with the brass bleed screw on top of the feed pump. When the feed line is free of air, especially at the suction side of the pump, the feed pump can be started.

4.4 Switch on the main switch (switch 1) and the feed pump switch (switch 2) Start the feed pump (switch SS 7).

4.5 Open valve 2 and regulate the flow (see Figure 3 for feed flow meter calibration curve).

4.6 Maintain a constant level in all tanks when the PACDAF unit is running.

4.7 Check the flow through the unit and control the level with valve 8 and with the height of the overflow pipe.

4.8 Switch on all stirrers. (switches 8, 9, 10, 11, 12 and 13). Start all stirrers (switches SS1, SS 2, SS 3 and SS 4).

4.9 Check that stirrers 1 to 4 are running properly.

4.10 Start stirrers 5 and 6. (switches SS 5 and SS 6). Check operation of stirrers.

4.11 Turn stroke lenght and frequency adjustment on all dosing pumps to minimum.

4.12 Obtain stroke lenght and frequency settings to obtain a specific flow from the nomograph in the manual.

4.13 Start the dosing pumps as required (switches 3, 4, 5, 6 and 7).

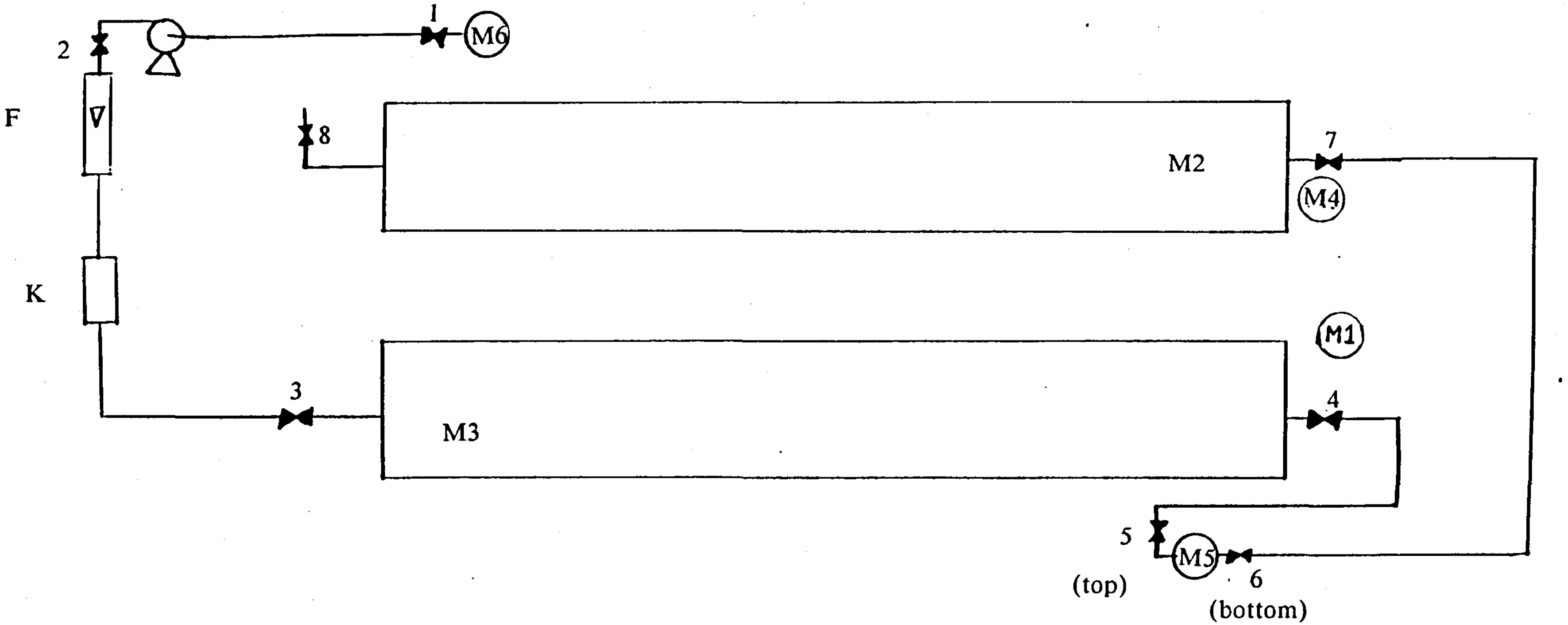
4.14 Disconnect the dosing line from the dosing point, set pump at full capacity and check whether pump is delivering.

4.15 Stop the pump, reconnect the dosing line, adjust the pump to the required flow and start

4.16 Check the operation of the PACDAF-pilot plant and make the necessary adjustments.

5. FLOCCULATOR ADJUSTMENT

Both flocculators are chain driven and the speed of the flocculators can be adjusted by changing the sprockets. The flocculators are standard fitted with the following chain drive:
Drive : 29 rpm x 13 teeth sprocket
First flocculator : 36 teeth sprocket
Second flocculator : 57 teeth sprocket.



M1, M2, M3, M4, M5, M6: stirrers 1 to 6

F: flow meter K: Kenix in-line mixer

FIGURE 2: Position of valves and stirrers

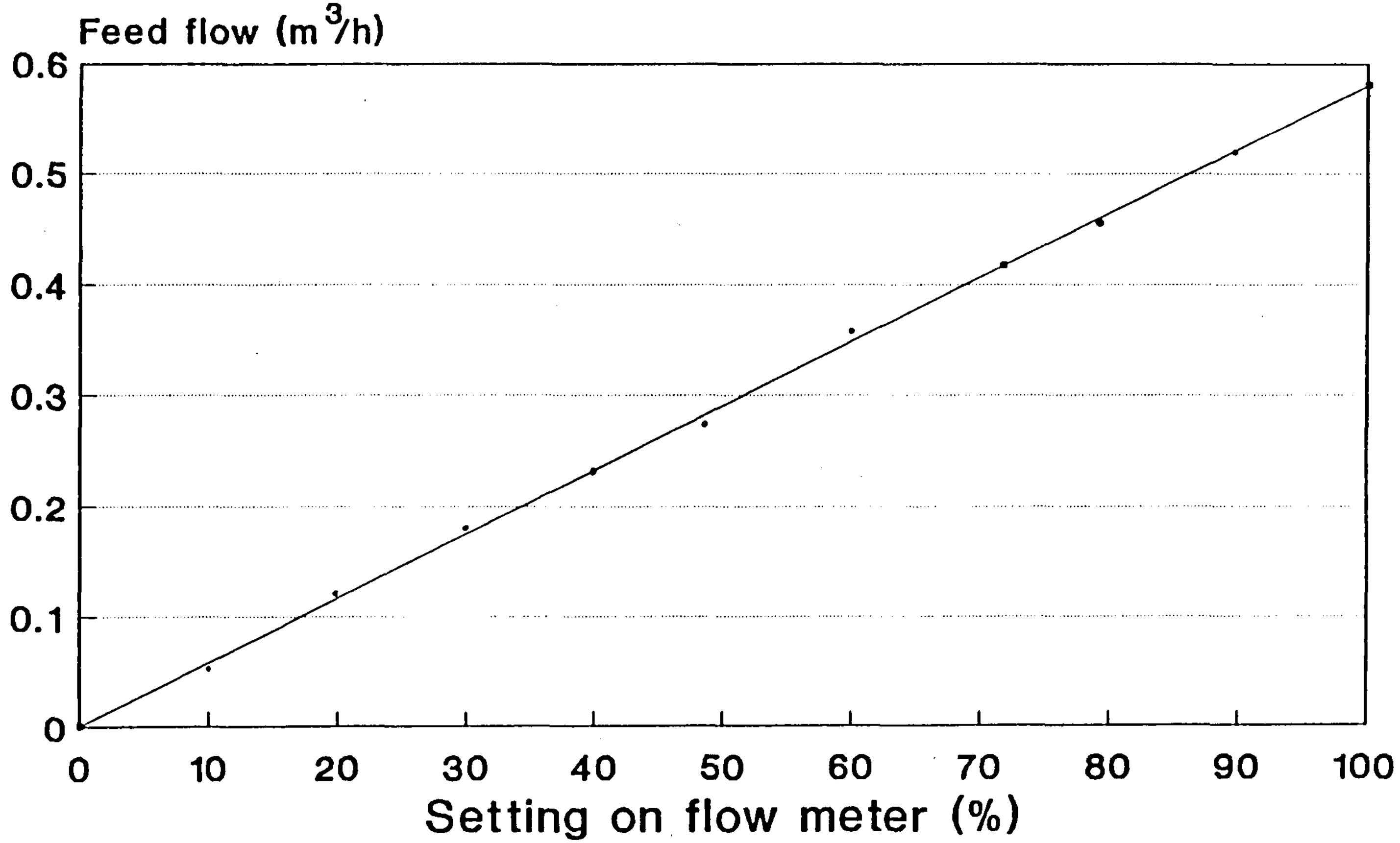


FIGURE 3 : FEED FLOW METER CALIBRATION CURVE

To change flocculator speed use the following formula to calculate the required sprocket for the flocculator:

$$\frac{\text{Drive sprocket teeth x drive rpm}}{\text{driven rpm}} = \text{driven sprocket teeth}$$

6. RECIRCULATION CONTROL

The recirculation is controlled by the needle valve on the nozzle. For further detail refer to the operation of the DWT 10 m^3d^{-1} perspex DAF unit.

ROOT MEAN SQUARE VELOCITY GRADIENTS

1. Contact tanks

Eu = = 2,5

$$G = \frac{Eu\ d^5\ n^3}{V}$$

$$G = \frac{2{,}5 \times 0{,}.13^5 \times 52^3}{0{,}045 \times 1{,}003.10^{-6}} = 17\ 005$$

d = 0,13 m

V 0,045 m^3

n = 52 rpm

2 Flocculators

2 flocculators are provided per DAF-cell. One running at 10,5 rpm and one running at 6,6 rpm

L = 0,9 m

b = 0,03 m

L/b = 20

K = 2,0 (Polasek)

A = 0,03 x 0,9 = 0,27 m^2

$$G = 7{,}25\ \frac{K\ n^3}{V}\ r^3\ A$$

10,5 rpm flocculator

G = 50 798 s^{-1}

6,6 rpm flocculator

G = 26 188 s^{-1}

LYS VAN BOEKE WAT IN DIE KLEIN BIBLIOTEEK GEHOU WORD

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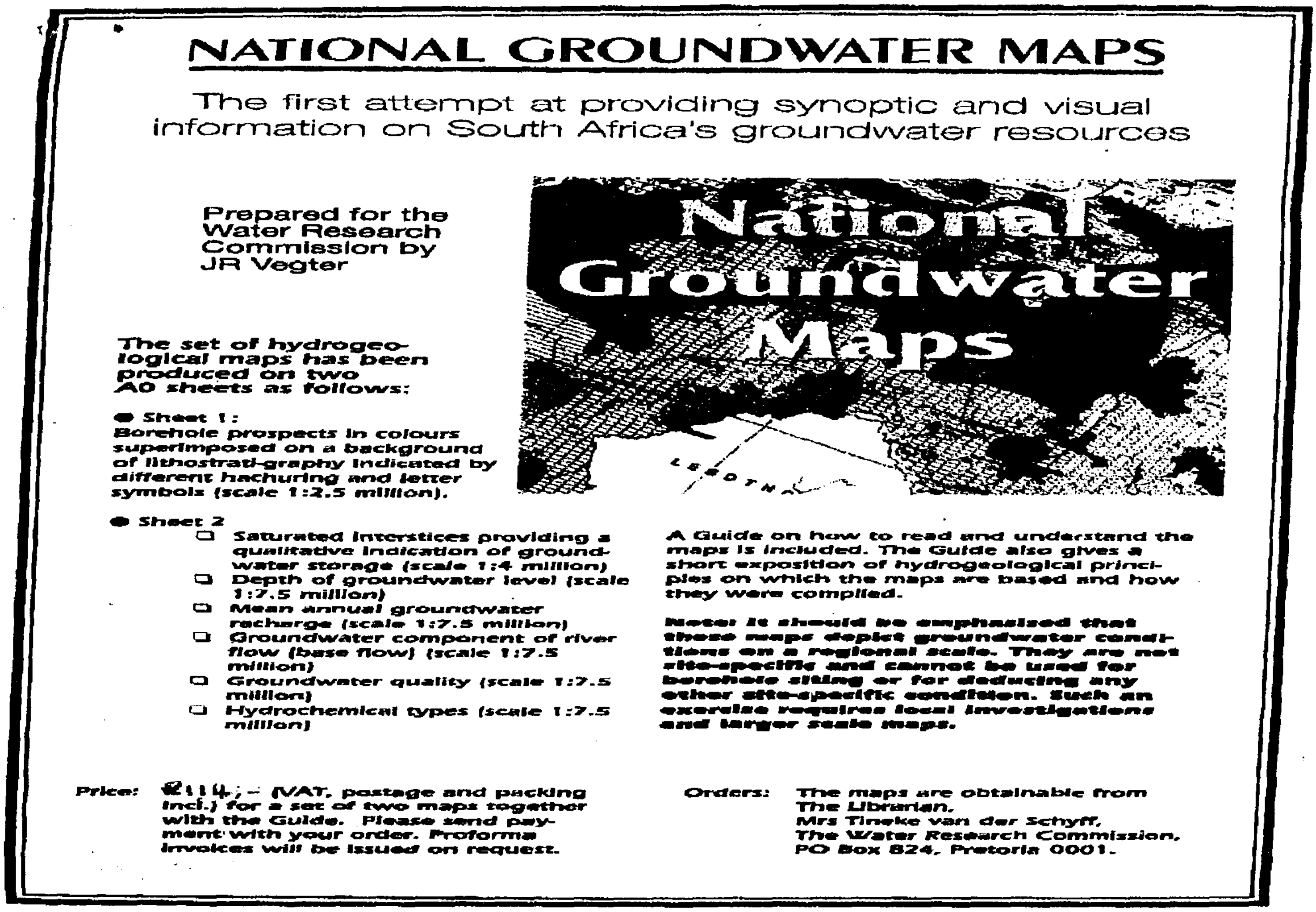

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The first attempt at providing synoptic and visual information on South Africa's groundwater resources

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Water Research
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