Sewage purification in South Africa - past and present

DW Osborn
City Health Department Laboratories, P O Box 1477, Johannesburg 2000, South Africa.

Abstract

Progress in the treatment of waste water in South Africa from the 1890's to the middle 1980's, is presented historically to approximately 1919. Thereafter, consideration is given to environmental aspects and developments taking place in various unit processes, including detritus removal, screening, sedimentation, sludge treatment and disposal, biological filters, the activated sludge process, algal systems, effluent polishing techniques, chemical treatment and marine disposal.

The pre-waterborne sewage era

Some of the problems faced by inland towns are typically illustrated by the experience of Johannesburg and Pietermaritzburg. In 1897, Johannesburg had in service a number of tank carts and other conveyances to carry away some 73 Mℓ/a of slops, as well as a much greater volume of bath water for dumping at Waterval Farm (Shorten, 1986). The pit privy and bucket were the norm in Pietermaritzburg before 1905, and household waste liquid was merely discharged into open street channels and drains for discharge to the Umzinduzi River. This led to a court case against the Council, which it lost, but provided stimulus for the construction of a proper works (Harris and Skinner, 1965).

The formative years - 1898 to 1919

Early sewage purification in South Africa appears to have been based on the septic tank. This system was introduced by the British military authorities for serving camps at Roberts Heights, and artillery barracks in Pretoria, Standerton, Potchefstroom and Harrismith. Septic tank effluent was treated in contact beds and irrigated (De Vaal, 1945).

The first municipal scheme designed in South Africa (1898) at Wynberg, commenced operation in January 1905. Sewage was passed through 38 mm fixed screens and then through a Wrexham rotary screen operated by a water wheel. After grit removal, the sewage passed to six rectangular filter beds with 1,14 m media depth fitted with rotating trough sprinklers which could be used either as contact beds or percolating filters. Regrettably, it seems that the filter beds were only operated during the wet season when the land was not capable of absorbing the septic tank effluent (De Vaal, 1945).

The honour of having the first operational sewage works fell to Bloemfontein, whose plant became operational in November 1904, two months prior to Wynberg. Effluent from the single open septic tank was treated on five primary filters (18,3m dia x 1,2m deep), followed by five secondaries of similar size. Thus, South Africa's first double filtration system was born, which could be used as either contact or percolating beds (De Vaal, 1945).

The Pietermaritzburg Works, built in 1908, provided the first departure from the rectangular form of septic and sedimentation tanks and the first to have separate sludge digestion facilities for raw sludge removed from conical-bottomed Dortmund type circular, primary sedimentation tanks. These works became derelict and 10 years after construction were entirely out of action. Not even the sedimentation tanks were used, as after screening, crude sewage was irrigated over land (Hamlin and Wilson, 1951).

The Lieutenant Governor of the Transvaal appointed commissioners to report on schemes for Johannesburg and Pretoria. In 1906 they recommended a scheme for the Johannesburg Klipspruit Works, consisting of a detritus tank and two septic tanks, with provision for irrigating the effluent. This was not carried out and sewage was irrigated on land untreated. After two years, however, in 1908, detritus chambers and a sedimentation tank based on the Travis (see "Sedimentation" p. 142 for description of Travis tanks) principle were installed, and in 1909 additional conventional sedimentation tanks had to be added (De Vaal, 1945; Hamlin and Wilson, 1951). This system was used by the City up to 1928, when a start was made with the introduction of biological filtration (Hamlin and Wilson, 1951). Irrigation of decreasing volumes of settled sewage was practised until the introduction of the Water Act No. 54 of 1956 (JCEAR, 1956).

In the case of Pretoria, the Government refused to allow ground outside the municipal area to be acquired for sewage treatment processes. The site permitted on the banks of the Apies River was too small to allow irrigation of the ***unsettled*** effluent from four 24,4m dia x 1,8m deep, circular biological filters, and in 1909 the Governor of the Transvaal granted permission for the Pretoria City Council to become the first local authority to discharge purified effluent directly to the stream (De Vaal, 1945). The Pretoria Works was commissioned in 1912, and the filters then installed are still providing a satisfactory effluent 75 years later.

Soon after commissioning the plant, it was noted that banks of humus were forming in the Apies River (Hamlin and Wilson, 1951). Appropriate remedial measures taken at a later date eliminated this situation.

Water pollution control legislation

From the foregoing, it will be apparent that land irrigation of effluent was considered to be the main means of preventing stream pollution. The Union Health Act No. 36 of 1919 strengthened this situation, as it prohibited local authorities from discharging effluents into a river, irrespective of the quality. The Chief Health Officer of the Union, in terms of this Act, normally required fully purified effluents to be irrigated at the rate of one million gallons/100 acres.d. This is equivalent to 4 090mm of irrigation water per annum, in addition to rainfall, and obviously did not prevent a large amount of runoff from the land to stream. This legislation also permitted the Minister of Health to lay down standards for purified effluents, but these powers were never exercised.

---

*Revised paper. Originally presented at the Institute of Water Pollution Control Conference in Port Elizabeth in May 1987.
Received 25 January 1988.

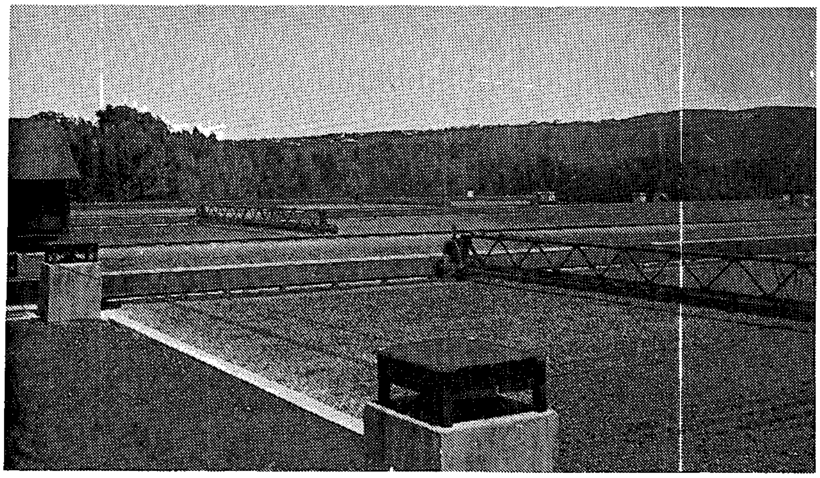
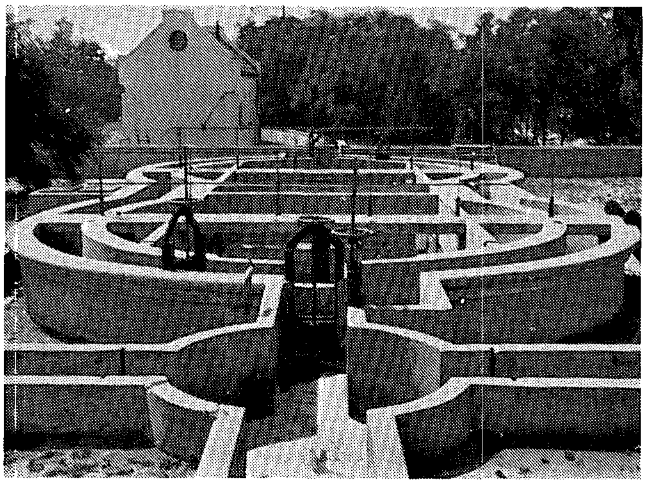


Figure 1
1931 – Johannesburg Bruma Works rectangular filters. Distribution arm driven by Pelton wheel (Courtesy of City Engineers' Dept., Johannesburg).

Figure 2
Imhoff tanks at the Athlone Sewage Treatment Works, commissioned about 1921 and in use until 1951 (Courtesy of City Engineers' Dept., Cape Town).



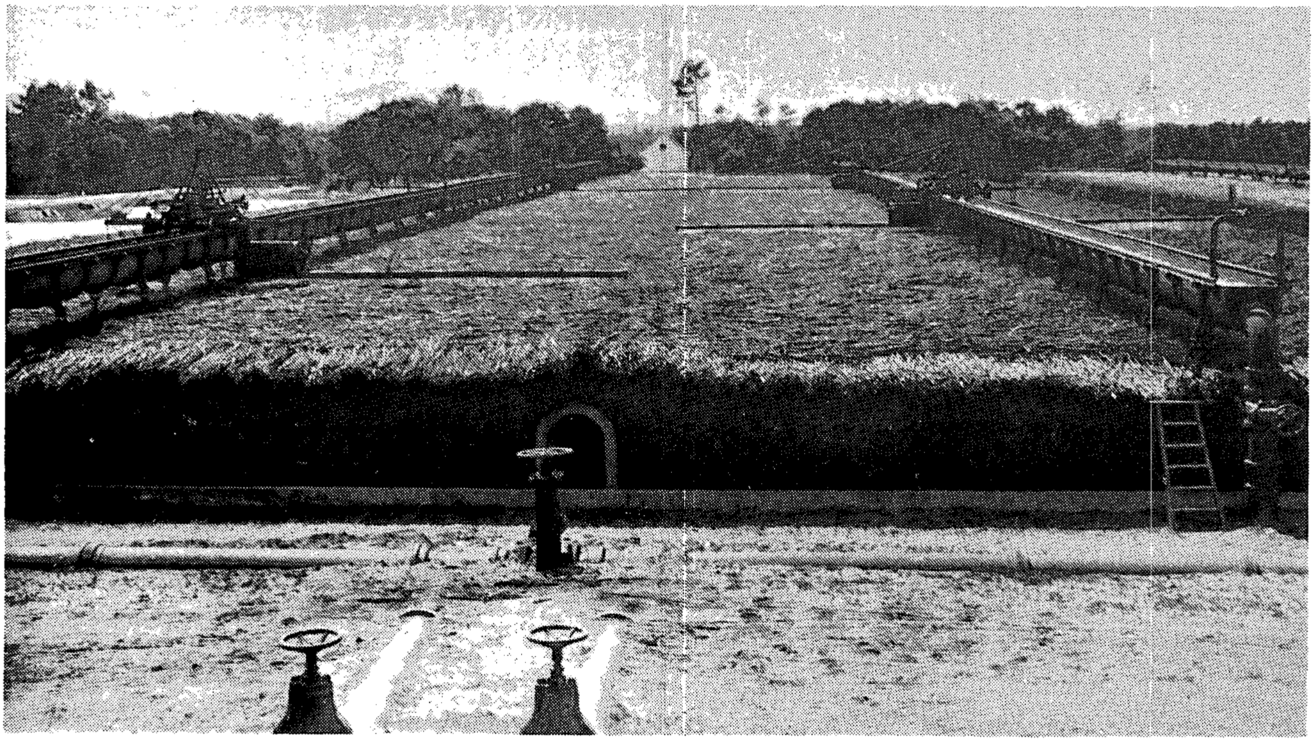


Figure 3
"Brushwood Filters" treated effluent from the Imhoff tanks. Broad irrigation followed and the drainage was directed to the Vyekraal River and thence to Table Bay (Courtesy of City Engineers' Dept., Cape Town).

In 1951 the South African Bureau for Standards also published standards for the discharge of effluent to streams, but these were more in the form of a guide and there was no compulsion to enforce them.

The Water Act No. 54 of 1956 basically reversed the above requirement and made it obligatory to discharge purified effluents to the watercourse. Permits were required to use water for agricultural purposes and to discharge effluents not complying with the quality standards. These were finally published in Government Notice No. R583 of 1962 and revised in Government Notice No. R991 of 1984. Both these Acts and in particular, the Water Act, which was further modified by the Water Amendment Act of 1984, exerted a marked influence on the methods of sewage purification subsequently adopted.

The area within the Republic of South Africa is approximately 1 226 000 km^2 and is occupied by a multi-ethnic society enjoying varying degrees of financial affluence. Sewage purification facilities must therefore be tailored to the resources of a particular community. Definite overall trends in the development of sewage purification are not readily discernible and will also vary from inland to coastal areas. As an illustration of this point, pre-1900 technology, namely contact beds, was used from 1949 for a number of years, to partially purify sullage water arising from an emergency camp in Moroka, in the middle of the highly urbanised area around greater Johannesburg.

In these circumstances it is believed that overall developments are best traced by examining advances in the constituent processes. Where examples of particular processes have been cited, these are meant to be illustrative only and are by no means comprehensive.

Preliminary processes

Grit removal

Harris and Skinner (1965) reported the installation of a special stone trap at the Darvill Works in Pietermaritzburg. At other works a whole variety of grit removal devices have been used, including manually cleaned longitudinal channels, horizontal aerated units and vertical vortex designs. Two basic approaches to grit removal are evident, viz. removal of only the coarser material which is relatively free of organic matter for burial and specifically catering for the easy removal of fines from digesters (Hall, 1963) or the removal of fine and coarse grit, washing out organic matter and incinerating the residue. Harris (1976) describes a rotary hearth incinerator at the Darvill Works and a City of Cape Town brochure (1983) records the incineration of grit at the Cape Flats Works.

Screening

Vertical bar screens are in widespread use; hand raked at small installations, and mechanically cleaned at larger works. A mechanically raked rotating bar screen is to be found at the Kwa Mashu Works (Durban, 1973). Johannesburg installed comminutors on a number of its works and experienced heavy wear on the cutting components, which was ultimately minimised by coating the drum with weld deposited tungsten carbide (JCEAR, 1960/61). Other devices such as the Barminutor and Rotograter were tried but were unable to stand up to the heavy load (JCEAR, 1959/60).

Typical experience with this type of equipment was the development of long strings of rags which ultimately caused blockages in sludge pumps and digesters (Heynike, 1951).

Macerating pumps for screening appear to be more successful, although there is a growing tendency to keep screenings out of the system once they have been removed. These may be pressed into plastic sacks for burial or disposal on sanitary landfills (Johannesburg Goudkoppies Works) or incinerated (Durban, 1973; CCT 83/84). As a further protection for the air diffusers at the Johannesburg Bushkoppies Works, secondary 3,5 mm fine mesh horizontal, two-speed, rotating, stainless steel screens have been installed.

Grease and fat removal

Wilson (JCEAR, 1944/45) reported on wartime measures to recover fats from the Johannesburg Klipspruit Works. A sack was suspended in a manhole under the scum removing pipes and 550 to 636 kg/d of fat collected from 31,8 Mℓ/d of sewage. From this, about 68 kg of oleic and 136 kg of stearic acid was recovered. Laboratory staff showed that shaving soaps, creams and other cosmetics could be manufactured from this material. Recovery lasted for a year, with oleic acid fetching a price of ls 3d/lb and stearic acid, ls 6d/lb.

Beekman (CCT 1984/5) and Bassett (CCT 1984-85) have reported that the Cape Town Athlone and Mitchell's Plain Works have been equipped with air flotation devices to remove fat, which was then subjected to acid digestion prior to being disposed of to conventional digesters.

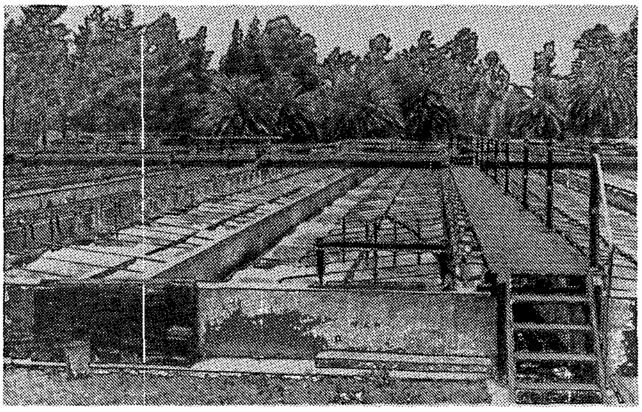


Figure 4
Johannesburg Bruma Works (1935) diffused air plant. Ridge and furrow system with plate diffusers
(Courtesy of City Engineers' Dept., Johannesburg).

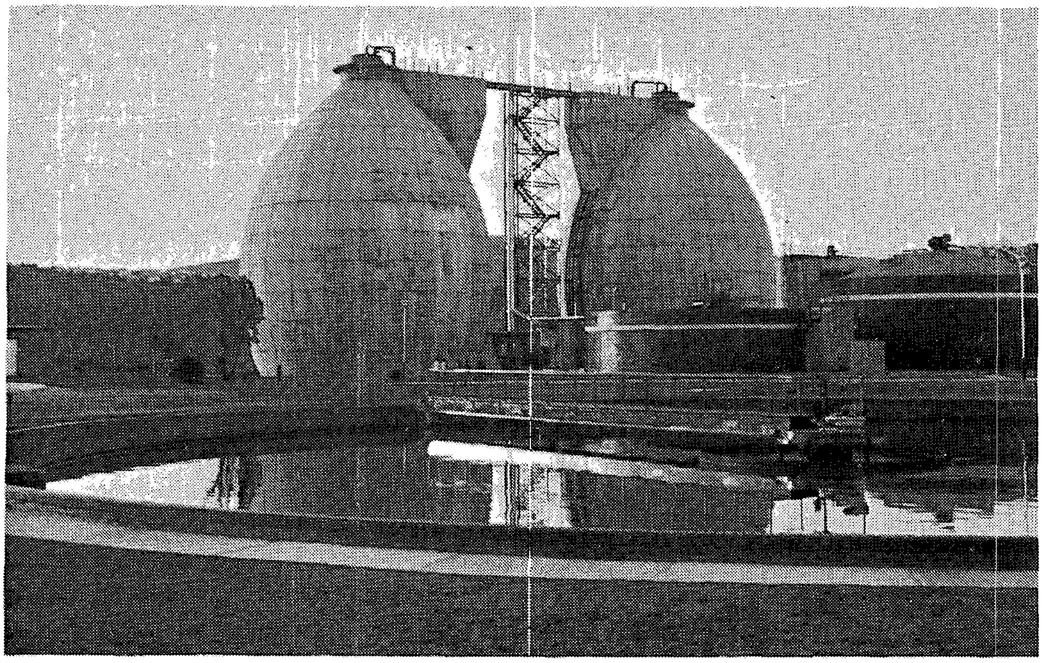


Figure 5
Extensions to Darvill Purification Works in Pietermaritzburg in 1978. Two new 4 500 m³ eggshaped sludge digesters with old digesters on the right, sludge prethickener in centre and original primary clarifier in foreground (Courtesy of City Engineers' Dept., Pietermaritzburg)

Environmental aspects

Hamlin and Wilson (1951) have recorded that "very bitter and prolonged complaints arose from the residential areas" near the Johannesburg Bruma Works, which was commissioned in the early 1930's (Fig. 1) and (Fig. 4). Remedial action taken included covering all sedimentation tanks, screens and detritus removal facilities, with a building from which air was extracted through an Ozonair Plant. Similar action was also taken at the Delta Works (JARSD, 1933/34). Fan-type jets distributing water over stone percolating filters at Bruma, were changed to solid type jets to minimise odour emission, and foul air from the primary sedimentation house was successfully deodorised by using it as a source for the air compressors supplying air to the diffused air activated sludge plant (JARSD, 1932/33).

Barnard (1962) described the adoption of a similar technique to artificially ventilate enclosed filters at the Germiston Rondebult Plant in 1958. Release of hydrogen sulphide from outfall sewers can be minimised by pure oxygen addition to the sewage, as practised at the Goudkoppies Works (Borland, 1987).

In the early 1930's, chloride of lime was added to the sewer leading to the Johannesburg Bruma Works and chlorine gas at two points of the outfalls leading to the Cydna Works (JARSD 1932/33).

The commissioning of the Port Elizabeth Fishwater Flats water reclamation works in May 1976 heralded an era of improved architectural treatment of works structures, to relieve the stark engineering austerity of purification works and make them aesthetically acceptable to the adjacent residential areas.

Increasing attention is currently being given to noise emanating from purification works. Severe problems have been experienced at the Kempton Park Works, with a system of overhead ducting connecting Roots-type blowers to the aeration tanks (Kolbe, 1986). The more recently installed large, diffused aeration systems, at Cape Town's Cape Flats Works, the Johannesburg Bushkoppies Works, and the Pretoria Rooiwal Works, have a minimal number of large blowers installed in an acoustically designed building, with special precautions being taken not to transmit vibration to the air distribution mains.

Sedimentation

Two-storey tanks

Early forms of primary clarifiers in South Africa often took the form of two-storey tanks, where the upper sedimentation chamber had a retention time of 1,5h and where the deposited sludge dropped through slots into the lower liquifying compartment, designed to hold a six month's supply of sludge. Travis developed such a tank in 1903 and one was installed at the Johannesburg Works in 1908 (De Vaal, 1945; Hamlin and Wilson, 1951). About 20% of the influent flow was allowed to pass into the lower compartment and effectively elutriate fermentation products (lower fatty acids) from the liquified fermentation products. This mode of operation enhanced solids separation in the upper chamber but resulted in an increased load of soluble material being added to the clarified sewage. It is of interest to note that the principle of this technique was re-introduced in the early 1980's by Barnard (1984), and Pitman, as reported by Nicholls *et al.* (1984), who recycled primary sludge to the head of the works to elutriate soluble materials to enhance biological nutrient removal. Pitman (JCEAR 1984/85) noted that an additional advantage of recycling crude sludge, was the increase in concentration to 7% of sludge withdrawn from flat-bottomed, scraped tanks at the Johannesburg Northern Works. A concomitant decrease in gas production was, however, also noted.

The Imhoff tank, developed in 1907 (De Vaal, 1945) is also of two-storey design, but differs from the Travis tank in that there is no outlet from the lower chamber, except for sludge. Two

Imhoff tanks were installed at the Athlone Works in Cape Town in 1921 (Fig. 2) and the effluent treated on Brushwood Filters (Fig. 3). A number of smaller units were installed in many different parts of the country (De Vaal, 1945).

Vertical flow tanks

In larger works the "Dortmund" type of upward flow tank has been extensively used. Originally developed in Dortmund, Germany, about 1886 (Garner, 1930) the upper part of the tank as originally designed, is square with vertical sides, and has an inverted pyramid-bottom with 60° sloping sides. In South Africa, it appears mainly as a circular modification with a conical bottom. Hall (1957) and Bergman (1958) both demonstrated the presence of thermal currents in this type of tank and Hall showed that this effect could cause tanks with a design retention time of 95 min, to have an effective detention period of 15 min.

To overcome this problem, he proposed the adoption of a two-stage tank, in the first stage of which flocculation and temperature equalisation took place, while in the second stage, quiescent conditions, free of thermal currents, ensured good settlement and easy removability of flotables.

At the Johannesburg Northern Works (Hall, 1963) six modified Dortmund tanks were constructed, but with the central stilling chamber replaced by a cylinder, open at the bottom with a volume of 30 to 40% of the total tank volume. The inlet is arranged tangentially to produce a slow rotation of the bulk of the liquid in the chamber, after which the liquid enters the secondary quiescent zone. This type of tank is more efficient than the conventional design, where the works are sited close to the drainage area and hourly temperature variations may exceed 2°C. Where long outfall sewers are in use the advantage is less marked. In the case of humus tanks where the influent was allowed to enter the tank tangentially on the outer periphery and exit through hanging troughs in the centre of the tank, an advantage of about 5% was noted over conventional tanks (Hall, 1963).

Hall (JCEAR, 1964/5/6) made further modifications to the above design, by introducing a flocculation cone into the enlarged central stilling chamber, similar to that described for the Johannesburg Klipspruit Works. A 9,4% advantage in suspended solids removal was claimed for this modification. Further attempts to improve flocculation by recycling sludge gave disappointing results regarding flocculation, and increased the COD of the effluent from 554 to 616 mg/ℓ. This technique was later used to enhance biological phosphorus removal.

Horizontal flow tanks

Site and space requirements have more recently played an important role in dictating the installation of horizontal flow tanks, for example,. Durban Central Works (Kinmont, 1966) and Johannesburg Northern Works (Keay, 1979).

Humus tanks

Earlier designs were traditionally upward flow circular tanks with a 60° conical bottom. Hall (1963) installed 24 tanks of 9,1m diameter with a 52° conical bottom at the Johannesburg Northern Works, half of which were reverse flow tanks in that the influent entered tangentially around the periphery of the tank, flowed into a central compartment, 7m dia x 2,1m deep and left this zone via centrally suspended steel launders. Over a period of 16 weeks the PV of effluent from these tanks averaged 15,8 mg/ℓ, whilst that from the remainder of the conventionally designed tanks was 16,6 mg/ℓ. The large areas of steel in these tanks proved expensive to maintain.

One humus tank at the Johannesburg Olifantsvlei Works was converted to a Banks (WRC, 1964) pebble bed clarifier. A perforated plate supporting a shallow bed (150mm) of gravel (6 to 9mm) was hung just below the water surface. Accumulated humus was removed by periodically dropping the level in the tank, thus causing a backwashing effect. Solids removal could be completed by hosing. Whilst an improvement in solids removal was noted, the additional maintenance costs mitigated against the extension of this concept to other tanks.

Activated sludge clarifiers

Circular clarifiers are most commonly used in South Africa, although square, pyramid-bottomed tanks were initially installed at the Johannesburg Bruma Works (Fig. 6). Disused 60° conical-bottomed, vertical rise primary settling tanks have been successfully used for the separation of extended aeration sludge at the Johannesburg Olifantsvlei Works. At two small extended aeration plants, Tongaat and Umdloti, on the Natal North Coast, 45° cones have been used (WSAE, 1985). At Borchards Quarry, rectangular tanks have been used (King, 1982).

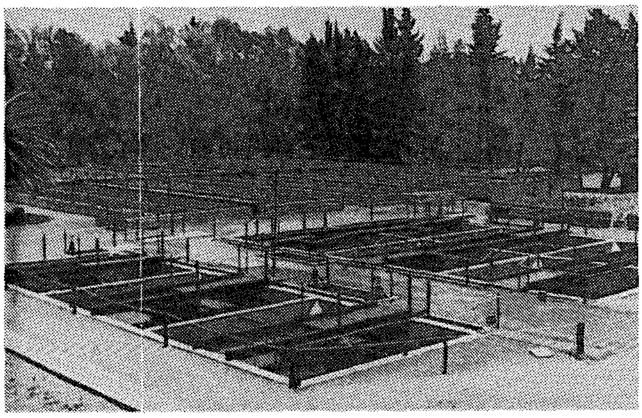


Figure 6
Bruma Works activated sludge plant
(Courtesy of City Engineers' Dept., Johannesburg).

Extremely shallow, radial flow tanks have been installed at the Durban Northern Works conventional activated sludge plant (Letcher, 1982). Tanks with a side wall depth of 1,8m have been found to be barely adequate at the nutrient removing Johannesburg Northern Works (Pitman, 1985), where filamentous sludge is encountered. Experience has also shown that scum removal facilities on such plants must be enlarged (Keay, 1984). The same author has also noted the difficulties associated with the operation of siphon sludge withdrawal systems, when individual discharges from each siphon cannot be seen. Pitman (1985) has proposed a revised design for final clarifiers of nutrient removing plants in which sludge is scraped to a consolidation zone in the centre of a clarifier, with a minimum side wall depth of 4m. Ekama *et al.* (1984) and Kerdachi and Roberts (1983) using the flux theory, have provided a more rational approach to the design of final clarifiers. In a limited number of plants, e.g. Kempton Park (Kolbe, 1975; De Lange, 1979) aeration, clarification and sludge return facilities are all integral in one tank. A similar design of plant at the Durban Northern Works has now been replaced, due to operational difficulties mainly associated with batch loading from the Porteous Plant described in the next section (Howes, 1986).

Sludge treatment and disposal

Mesophilic anaerobic digestion

The forerunner of mesophilic digestion was the septic tank and the two-storey sedimentation tanks described previously. The successful application of the principle underlying controlled separate digestion rightly falls to Mr M Lundie, the first chemist to be appointed in South Africa (1910), in charge of a sewage works, viz. Pretoria Daspoort Works (De Vaal, 1945). Two rectangular tanks were provided, one of which received all the raw sludge each day, for a period of 12 months, after which time it was allowed to remain dormant for a further period of one year. Whilst this was happening, the other tank was brought into use. By adjusting the pH of the sludge in one digester with lime, active digestion was brought about and this sludge was then used for seeding other digesters.

Early versions of digesters were usually rectangular and unheated. Improvements were brought about by heating through hot water coils and collecting gas under moving steel covers built on top of the tanks. A bank of such units was built at the Johannesburg Delta Works (JARSD, 1934/35) and later at the Klipspruit Works (JARSD, 1938/39).

A variety of scum breakers have been used, for example, rotating breaker arms (which soon failed), in the Dorr digesters at the Johannesburg Bruma Works, and rotating flails at the Rondebult Works, Germiston (Barnard, 1962). Prüss digesters which have a conically shaped bottom to ensure that the entire contents gravitate towards it, and a truncated cone top to minimise scum production, were installed at the Johannesburg Cydna Works (JARSD, 1930/31) and the Kimberley and Bloemfontein Works about the same time (Prüss Digesters, 1947). A modern adaption of this concept is to be found in the egg-shaped digesters developed by Oswald Schultze and described by Harris (1976), and installed at the Pietermaritzburg Darvill Works (Fig. 5). These are the first of their kind in South Africa and are of prestressed (post-tensioned) concrete construction. They are the height of a nine-storey building, with a 4 500 m^3 capacity and have ground access for sludge removal purposes. Even larger cylindrical shaped 6 200 m^3 prestressed concrete digesters with a ground level access and capable of operating at 50°C, have been constructed at the Cape Flats Works (Brand, 1981). Mixing is by gas recirculation. This procedure has also been adopted at the Johannesburg Northern Works, where some digesters have been fitted with four steel draft tubes into the bottom of which steam and gas are introduced. With regard to gas collection, the Boksburg Vlakplaats Works was the first to introduce a membrane type gas holder in South Africa (Louw and Basson, 1983).

Ambient aerobic digestion

Aerobic digestion was probably first practised at the Klipfontein Organic Products sewage works under the name of "Unigester" (ESTC, 1947) (SA Patent 1084/47). In the Huisman Orbal system described later, an additional channel may be added to further aerate clarifier underflow sludge, prior to disposing of it to sand beds for drying.

Neither of the above techniques satisfy the conditions proposed by the State Health Department, in their guidelines for the disposal of sewage sludge, which requires this material to be free of pathogenic organisms, virus and viable *Ascaris lumbricoides* ova (Oberholster, 1983). The following heat treatment processes aim at achieving these objectives:

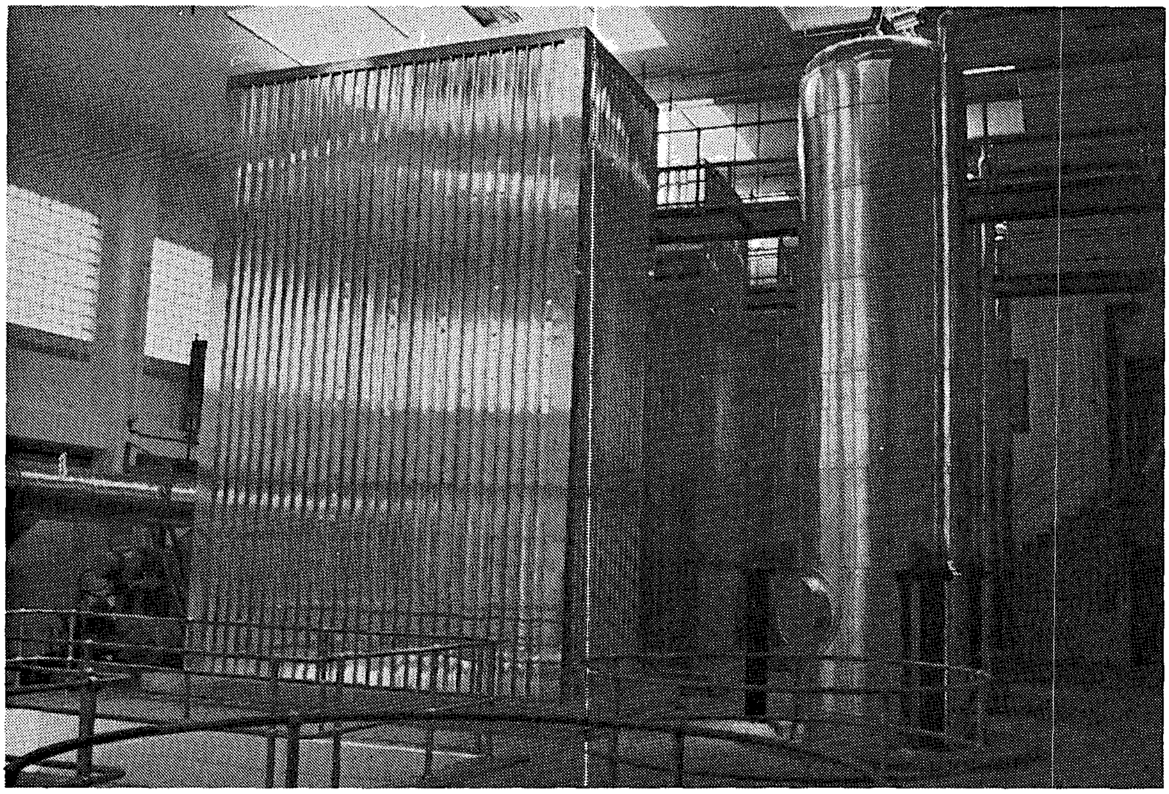


Figure 7
Porteous heat treatment plant, Southern Works, Durban, showing feed pump, heat exchangers and reaction vessels (1969)
(Courtesy of the City Engineers' Dept., Durban).

Thermophilic digestion temperatures in the range 50 to 55°C have been attempted at the Johannesburg Northern Works by means of submerged burners (JCEAR, 1964) in a pilot plant, but this experiment was abandoned in favour of a trial lasting 14 months, using direct steam injection into one full-scale digester (JCEAR, 1964/65). It was abandoned due to difficulty in operation and the production of malodorous sludge.

Pasteurisation facilities, the largest in Africa and capable of holding sludge at 70°C for 30 min, have been successfully operated at the Cape Flats Works (CCT, 1980). Prepasteurisation was found to be the most suitable (WRC, 1986) with no additional heat being required to maintain mesophilic digestion temperatures.

Unslaked lime addition at pilot-scale level to raw, digested and waste activated sludges, was attempted at the Johannesburg Olifantsvlei Works (Van Niekerk, 1980). Doses of 600 to 1 400 kg CaO/t of solids were required in order to reach and hold a temperature of 64 to 69°C for 1 h, required for the destruction of *Ascaris lumbricoides* ova.

Autothermal aerobic digestion

Pure oxygen added via the Vitox system to a 50/50 mixture of raw sludge and waste activated sludge in a 10 m^3 pilot plant at the Johannesburg Olifantsvlei Works caused temperatures to rise to 60°C. The pathogenic properties of the sludge were acceptable but the settling properties were virtually non-existent (WRC, 1984). Full-scale application is now being attempted at the Potsdam Works of the Milnerton Municipality, where aerobically digested sludge will be subjected to further mesophilic digestion to improve sludge settling characteristics.

Porteous process

Installed at the Durban Southern (Fig. 7) and Northern Works, the primary purpose of this process was to condition digested sludge (or raw sludge) at 2 100 kPa for about 45 min at 180°C, to make it suitable for dewatering by filter pressing (Howes, 1986).

Zimpro process

This process relies on conditioning thickened, macerated raw sludge at 2 200 to 2 800 kPa and 187°C in the presence of air. Phase separation is then induced by centrifugation. A large installation, 29 t dry solids/d, is still in operation at the Fishwater Flats Works, Port Elizabeth, whilst a smaller unit, 12 m^3/h, at the Potsdam Works, Milnerton, has made way for the autothermic process described above.

Incineration

Fluidised bed incinerators were installed in the 1970's at both the Durban Central Works (Durban, 1980) and the Port Elizabeth Fishwater Flats Works (PECC, 1978). High costs of auxiliary fuel have resulted in both units being decommissioned. Since 1984 (Odendaal and McGlashan, 1986) raw sludge from the Durban Central Works has been satisfactorily discharged to sea via a submarine outfall. Zimpro sludge from the Fishwater Flats plant has been used in brick manufacturing and for agricultural purposes (Slim, 1986). At the Durban Kwa Mashu Works, two Hereschoff-type multiple hearth furnaces burning thickened, centrifuged raw sludge were installed in the early 1970's (Howes, 1986).

Digested sludge has been dewatered traditionally on drying beds using sand, ash, and porous tiles made from clinker or even sawdust (Harris and Skinner, 1965). Concrete bottomed drying beds were probably first installed at the Klipfontein Organic Products Works and the South African Railways Esselen Park Works (ESTC, 1947). Louw and Basson (1983) have installed similar units at the Boksburg Vlakplaats Works, with provision to withdraw liquor at different levels, and at the Johannesburg Northern Works interlocking paving bricks with no retaining walls have been used to dry thin layers of belt pressed waste activated sludge (D and H, 1986). Whilst the latter company was operational, this sludge was irradiated with accelerated electrons with the ultimate aim of proving the suitability for incorporation into cattle feeds.

Digester gas, apart from being used to heat digesters, has also been used as a fuel for gas engines generating electricity, the earliest application of which was probably at the Johannesburg Bruma and Delta Works (JARSD, 1934/35). Two dual engines were installed at the Germiston Rondebult Works (Barnard, 1962). More recent applications have been at Sebokeng and Kempton Park (Kolbe, 1986). Pollock (JARSD, 1934/35) has described the use of sludge gas as a motor vehicle propellant. The use of sludge gas for the manufacture of cyanide was first started in 1946 and currently, the total production of the Johannesburg Klipspruit and Olifantsvlei Works is used for this purpose (Hamlin and Wilson, 1951).

Biological filters

Brodish (1985) has estimated that about 50% of the works in South Africa use biological filters, whilst 10% make use of biological filters and activated sludge systems. The early days of filters in which they could also be operated as contact beds, have already been described. Claims that greatly increased loadings were possible in forced down draft enclosed filters, led to considerable interest in this field. In Johannesburg in 1936, a 12,2 m dia x 1,83 m open filter was compared with a Prüss enclosed ventilated filter, 12,2 m dia x 3,66 m high, and it was concluded that in winter the enclosed filter could purify about 3,5 times the flow per unit area treated by the open filter. Performance was similar in summer. Forced draft ventilation was considered essential (JARSD, 1940). This latter finding was not confirmed by Vosloo and O'Reilly (1945), describing the performance of two enclosed filters constructed in 1936 at the Springs Anchor Works. A similar comparison was carried out at the Germiston Rondebult Works on filters constructed in 1937, and this city ultimately enlarged its works with 22,86 to 30,45 m dia x 4,27 m deep artificially ventilated, enclosed filters (Barnard, 1962). In 1939, extensions to the Cape Town Athlone Works were initiated and included two biological filters (one primary and one secondary, enclosed with forced ventilation). Further extensions also included enclosed filters (Morris, 1971). In 1957 the first below ground level filter in South Africa was commissioned at the Springs Anchor Works. No difference in performance was noted when the ventilation shafts were closed off (Heynike, 1954).

In summarising some of the Johannesburg experience with biological filters Osborn (1979) records that double filtration permitted a 12% increase in load compared to recirculation, and that the latter in turn showed a 37% improvement over single filtration. Periodicity of dosing and intermediate humus removal in the double filtration mode, which was ultimately adopted in its second generation works, was found to be relatively unimportant.

Attention is drawn to the enchanced nitrification produced by this process and the concomitant drop in alkalinity (Osborn, 1965).

Performance of biological filters is critically dependent on size and composition of the media. Vosloo and O'Reilly (1945), have reported that a 3,66 m deep filter at the Springs McComb Works, filled with 19 to 38 mm stone, had to be emptied and refilled with 38 to 50 mm stone.

Round, river-worn cobbles have been used at the Paarl Works (Blerch and de Villiers, 1971) and plastic media at Lydenburg (Skinner, 1986) and the Cape Town Athlone Works, as roughing filters ahead of the main biological filter plant.

Slag media used in the Vereeniging Leeuwkuil and Germiston Dekama Works in 1972/73, rapidly showed signs of leaching soluble fluoride salts and a diminution in the volume of the media. Another source of slag, also from the Vereeniging area, has been used at the Sebokeng Works and Vanderbijlpark Works and has given acceptable service (Engels, 1986).

Bio-disc filters have found application at holiday camps and for treating effluent from septic tanks. The largest bio-disc installation is at Medunsa, Ga-Rankuwa (Murray, 1987).

Activated sludge

The first **conventional** activated sludge plant to be installed in South Africa, was at the Boksburg Hospital in 1921/22, followed by a similar plant in 1927 at the Elsenburg Agricultural College in the Cape. These in turn were followed by a temporary plant at the Pretoria Police Training Depot (De Vaal, 1945). In the early 1930's three small plants, each intended to treat 0,45 Mℓ/d of settled sewage, were installed at the Johannesburg Bruma Works in 1932, (Fig. 8) and were based on the diffused air principle, Simplex mechanical aeration concept and the Spiroflow (Hartley) system (Hamlin and Wilson, 1951). The diffused air plant gave the best results and it was decided to proceed with the construction of ridge and furrow, plug flow type activated sludge plants (Fig. 4), aerated with plate-type diffusers at the Johannesburg Bruma and Delta Works. Both these works were commissioned in 1935 (JARSD, 1934/35). Samson (1950) has described how these alundum plates, which were blocked with oil deposits from the air compressors, were cleaned in 1949, by heating the plates to distill off the oil. The main function of the Bruma Plant was to deodorise the influent sewage. Nitrified effluent was fed to the rectangular biological filters via Pelton wheel drive distributors at night to "sweeten" them after receiving a heavy daytime load.

Process modifications were introduced into the operation of the Johannesburg Bruma and Delta Plants in 1941, when additional aeration capacity was installed to permit 25% of the tank volume to be dedicated to the re-aeration of the sludge returned from the clarifier (JARSD, 1940/41). At the same time increased plug flow conditions were introduced on one unit of the Delta Works when a middle, dividing wall was installed on the 6,1 m wide channels, to create a longer path of travel. Air consumption was reduced from 43 m^3/m^3 to closer to 25 m^3/m^3 (White, 1953).

Step addition of feed sewage was tried at the Johannesburg Delta Works in October 1957, but had to be abandoned due to rising sludge in the final clarifiers. A similar experiment was carried out at the Bruma Works over a period of eleven months and multiple points of addition of sewage were found to offer no advantages over single point addition, and resulted in reduced nitrification (Osborn, 1961).

A ***"fill and draw"*** activated sludge process was introduced at the Johannesburg Cydna Works in 1940 and for the following 7 years the works was operated in this mode. Peak settled sewage flows to this works were stored in a multiple pass ridge and furrow, plate diffuser, aeration plant until the early hours of the morning when the aerators were turned off and the settled nitrated effluent decanted to the biological filter plant.

In 1977 a similar technique was used at the Germiston Rondebult Plant to relieve load on the biological filters. A temporary surface aerated activated sludge plant was created in a plastic-lined earth dam and the settled effluent returned to the filter plant. It is of interest to note that the plastic lining disintegrated relatively quickly and ten years after construction, the plant was still operating in the earth basin. Aeration capacity was supplemented with pure oxygen from July 1983 to October 1985 after which time the load dropped (Van der Merwe, 1987). In 1947 the Cydna Plant was converted to a conventional activated sludge unit until 1954, when it was used for experimental purposes. One modification involved alteration to the ***contact***

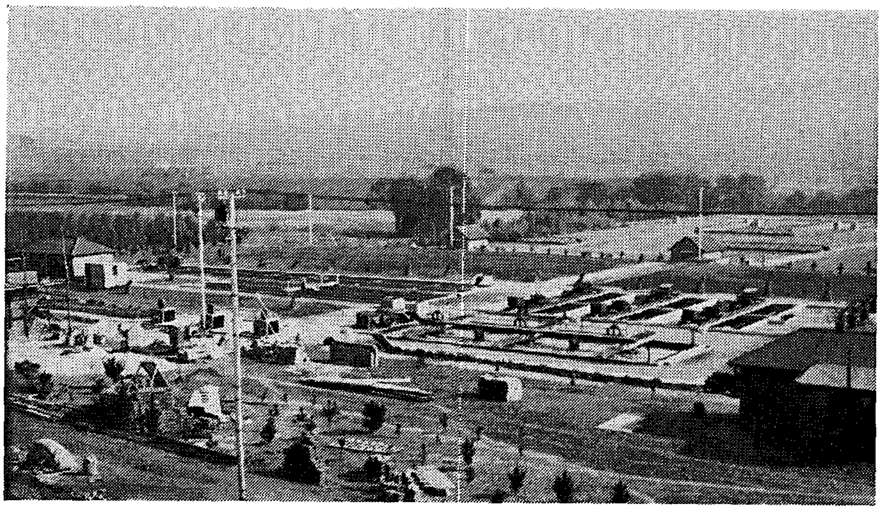


Figure 8
Experimental 0,45Mℓ/d activated sludge plant at Johannesburg Bruma Works – early 1930's – incorporating diffused air, simplex and spiroflow (Hartley) system
(Courtesy of City Engineers' Dept., Johannesburg).

stabilisation or ***Biosorption*** mode of operation. Although three times the flow over conventional operation could be treated, additional final clarifier capacity was required with a maximum upflow rate of 1,4 m/h. Clear, low COD, but non-nitrified effluents were easily obtainable (Osborn, 1961).

Two stage, two sludge mode of operation was introduced at the Cydna Plant in 1957, with 5 h and 11,5 h retention being provided in the primary and secondary aeration chambers respectively. Difficulties were experienced in settling large volumes of high sludge age nitrifying sludge in the primary clarifiers and this mode of operation was discontinued (Osborn, 1961). This same technique was successfully tried at the Kempton Park Works in 1968 and introduced into subesquent extensions, and to the Germiston Waterval Works in 1978. Both plants receive high strength industrial effluents. Primary and secondary aeration basin retention times are of the order of 2 h each at the Kempton Park Works.

Extended aeration has traditionally been reserved for package plants, including those used by the gold mining industry underground and for small works. This system is used in the Pasveer (1959) ditch. Horizontal aerators were first installed in South Africa in the late 1960's (Howell, 1983). The same author has described the Verwoerdburg Works treating 8,1 Mℓ/d, as the largest Pasveer ditch in South Africa. The Huisman Orbal variation of this system has the aeration compartment divided into a number of endless channels forming a succession of orbal tracks fitting neatly into one another, interconnected by ports and aerated by means of a number of horizontal shafts carrying perforated discs. Bellville (9 Mℓ/d) may be quoted as a typical example of such a plant. The Carousel variation permits vertical shaft aerators to be used in a deep section of the ditch to transfer oxygen, for example, in 1973 at Heidelberg, Transvaal (1,36 Mℓ/d) (Bergman, 1975).

In the early 1970's, capital became an extremely scarce commodity and it became economically advantageous to build much larger extended aeration plants, for instance, the 80 Mℓ/d Johannesburg Olifantsvlei Works was constructed as four completely mixed compartments in series and designed for nitrification (Trim, 1982). This plant has successfully treated 130 Mℓ/d.

Nutrient removal activated sludge systems are now being installed with increasing frequency. The humble beginnings of this process in South Africa took place at the Johannesburg Bruma Works in the early 1930's. McLachlan (1936) reported on problems being experienced in primary sedimentation tanks, when waste nitrifying activated sludge was co-settled with raw sewage. It was left to Dr A Key of the Institute of Gas Engineers, during the discussion of this paper, to identify that this phenomenon was due to the reduction of nitrate to nitrogen gas, which rose to the surface carrying sludge with it. It is of interest to note that ozonated air was added to activated sludge under laboratory conditions in an attempt to alleviate this problem. Microscopic examination after 15 min aeration, however, showed that the visible organisms were still very much alive.

Trevelyan (1948), in further investigations of this problem, defined the requirements for denitrification as a source of nitrate, activated sludge and a carbon source such as sewage or sewage/soap/or sodium acetate. Barnard (1974), as a researcher at the Council for Scientific and Industrial Research, adapted these principles into a compartmentalised system named the Bardenpho process. The inclusion of an anaerobic zone also enabled this process to remove phosphates. The first large plant to be commissioned using this process was the Johannesburg Goudkoppies Works in 1978.

Nicholls (1977) demonstrated enhanced phosphate and nitrogen removal at the two-stage extended aeration Johannesburg Alexandra Plant, by periodically switching off aerators for a number of hours in the primary basin. Venter *et al.* (1978) successfully used the same techniques at the four-stage Johannesburg Olifantsvlei Works. Kerdachi and Roberts (1980) have shown that excellent results can be obtained consistently over many consecutive months, in the single basin Umhlatuzana (Pinetown) Plant, by creating anaerobic conditions overnight by switching off surface aerators. Under such conditions, these authors believe that reduced iron salts play a role in precipitating phosphate as a complex salt containing iron and calcium (Kerdachi and Roberts, 1983).

Paepcke (1983) reported that a number of first generation biological phosphate removal plants were not functioning optimally and this led to the development of the UCT and modified UCT processes by the University of Cape Town (Siebritz *et al.*, 1983). Both modifications aim at preventing the adverse influence of nitrates in the anaerobic zone. Gerber *et al.* (1982) found little advantage of these processes over the five-stage Bardenpho configuration. A number of small plants capable of using either the UCT process or its modified version, have been installed in South Africa, e.g. Bethal (Warner, 1985). One 50 Mℓ/d surface aerated unit at the Johannesburg Northern Works and one 37 Mℓ/d diffused air unit at the Bushkoppies Works, have been modified to have the following sequence of zones:

- a compartmentalised zone for endogenous denitrification of final clarifier underflow return sludge;
- a compartmentalised anaerobic zone to which the feed is added;
- a compartmentalised anoxic zone; and
- a final aeration zone (Pitman, as reported by Osborn *et al.* (1986).

Biological phosphate removal is enhanced when fermentation products derived from raw sludge are fed to the plant. Venter *et al.* (1978) and Osborn *et al.* (1986) have described improvements made to the phosphate removal performance of the Johannesburg Olifantsvlei and Northern Works, by the addition of liquors from an acid fermentation digester. Barnard (1984); Nicholls *et al.* (1984) and Osborn *et al.* (1986) have described the fermentation of sludge in the primary clarifiers and the recycle of sludge for elutriation purposes.

Waste sludge from nutrient removal plants requires to be handled aerobically if phosphate is not to be released. Current practice at the Johannesburg Northern and Goudkoppies Works, is to carry out the initial concentration by means of dissolved air flotation, and to further dewater the float by means of belt pressing.

Activated sludge treatment of biological filter effluent has been designed into the Pretoria Rooiwal Works for biological phosphate removal (Barnard, 1986). A similar situation exists at the Cape Town Athlone Works, where it is proposed to augment the biodegradable carbon of the filter effluent with a bleed-in of settled sewage, before treatment in the activated sludge unit (CCT, 1984).

Filamentous growths giving rise to bulking sludges, were first noted at the Johannesburg Bruma Works (JARSD, 1932/33). Low oxygen concentrations were considered a contributory cause. No further reference to this problem is made after re-aeration of the secondary clarifier sludge was introduced in 1941. Blackbeard and Ekama (1984) found that bulking problems were still very generally prevalent in second generation activated sludge plants. Controlled chlorination of activated sludge as recommended by Jenkins *et al.* (1982) has been used by various local authorities with varying degrees of success.

Osborn *et al.* (1986) have reported on the unsuccessful introduction of an anaerobic selector into one 50 Mℓ/d module of the Johannesburg Northern Works. Wakefield and Slim (1987) have reported on the successful introduction of an aerobic selector at the Port Elizabeth Fishwater Flats Plant, while Pretorius and Laubscher (1987) have promoted a selective flotation process for controlling scums.

Algal processes

Maturation ponds started to receive considerably more attention after the promulgation of regional standards for effluents in 1962. Bolitho (1965) concluded that "the most economical means of obtaining a high chemical standard capable of effecting considerable improvement in most rivers in southern Africa will usually be a combination of biological filter installation and maturation ponds".

These were widely adopted and their effectiveness was assessed (Drews, 1965).

Bird life in the vicinity of maturation ponds generally shows a marked increase and 57 identifiable species have been noted at the Cape Flats Works, where the total number of birds counted was in excess of 20 000 (CCT, 1980). Benjafield (1960) has reported that more than 454 kg of fish/acre per annum have been obtained from certain ponds in Cape Town.

African Explosives and Chemical Industries have used a system of multi-stage ponds with decreasing depths, to remove an estimated 200 kg/d of dried algae for use as a cattle feed, from one hectare of ponds at the Modderfontein factory, where high concentrations of nitrate are present in the factory effluent (WSAE, 1981).

Aerobic oxidation ponds also started to proliferate in the early 1960's, largely as a simple, inexpensive means of treating sewage from small communities, in which no separate facilities were required for sludge handling. The algal-laden effluents produced may only be used for agricultural purposes. This system has also been used as an initial, but temporary step, whilst the construction of a permanent plant is in progress. On the completion of such works, the ponds are usually converted to function as maturation ponds.

Anaerobic/aerobic systems were pioneered largely by Abbott (1962). The Muizenberg and Wynberg schemes commissioned in December 1959 and May 1960 were, by 1963, treating 27,3 Mℓ/d on 40,5 ha. This scheme embodied a recycle of oxygen and algal-laden water back to the head or anaerobic zone, which eliminated any smell nuisance. The scheme was so economical and successful that it was modified in 1964 to a system of sector-shaped ponds, each about 16,2 ha with a water depth of not less than 1 m. Six ponds were arranged in the form of a circle, each forming a sector of similar size (Morris, 1971). These ponds ultimately became maturation ponds for the new Cape Flats Works commissioned in 1980/81.

In 1964 the Durban Corporation canalised the Umlaas River at Chatsworth and constructed a similar temporary system in the old river bed, with two specifically designed anaerobic ponds to which algal laden water from subsequent ponds was added to prevent odour formation (Van Eck and Simpson, 1966).

Effluent polishing systems for river discharge

Slow sand filters were probably the earliest form of tertiary treatment and are typified by installations at the Johannesburg Cydna and Delta Works in the early 1930's. Periodic resting is necessary when operating this system. *Hamlin filters* (Fig. 9), developed by C H Hamlin of Luton, England, and described by Hamlin (1949), provided for reverse flow capabilities and were meant to carry out the dual function of a humus tank and a slow sand filter. The media consists of 150mm sand, 75mm of 12mm stone, 75mm of 25mm stone and 75 to 150mm of 25mm stone. In order to break up the humus formed on the surface of the sand, squeegies are hung from a frame supported on portable carriages, which run in guide channels built into the filter walls. From the early 1940's, forty of these units were constructed at the Johannesburg Klipspruit Works, for supplying cooling water to the Orlando Power Station. Filtration head required was 250mm.

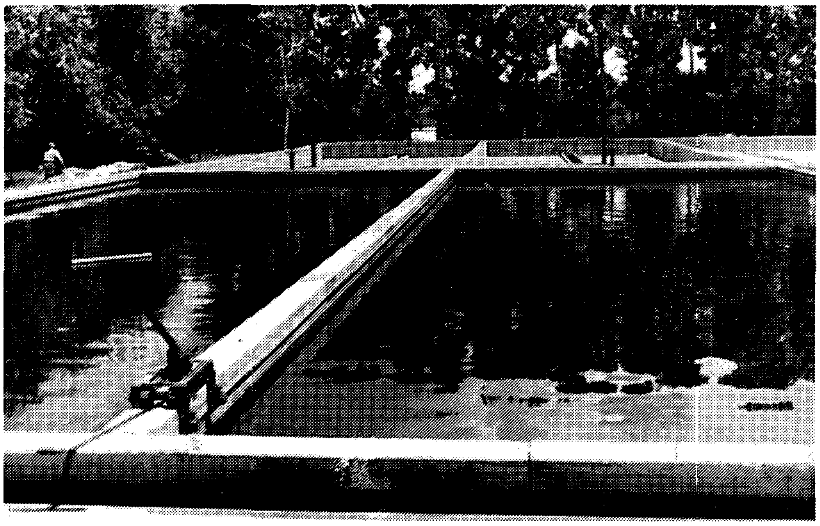


Figure 9
Hamlin sand filters, showing squeegie, at Johannesburg Klipspruit Works in early 1940
(Courtesy of City Engineers' Dept., Johannesburg).

Rapid gravity sand filters were used at the Springs Anchor Works in 1945 to upgrade biological filter effluent for industrial use (Heynike, 1950). This system was also used to supply power station cooling water from the Pretoria Daspoort Works (Nicolle, 1957), and the Johannesburg Northern Works (Hall, 1963). An *automatic backwash filter* in which filtration and backwashing can occur simultaneously, was placed in service at the 20 Mℓ/d Vereeniging Leeukuil activated sludge plant in February 1985 (VTC, 1985).

A *microstrainer* to treat 4,5 Mℓ/d of humus tank effluent was installed at the Pretoria Daspoort Works in August 1953, as a pretreatment unit for rapid gravity sand filters (Nicolle, 1955), but was later abandoned in favour of increasing retention time of humus tanks.

Macrophyte (Aquatic Plant) Systems: Toerien and Walmsley (1979) have commented on the beneficial effects of natural reed beds below the Kempton Park Rietfontein sewage treatment works. Artificially constructed reed beds incorporating phosphate removal concepts, have been described by Alexander and Wood (1986) and small units have been installed at Mpophomeni Works in Kwa Zulu, Grootvlei Power Station, the CSIR experimental station in Pretoria and at the Johannesburg Olifantsvlei Works. *Grass bed treatment* with an application rate not greater than 3 000 m^3/ha.d has been described by Murray, 1987.

A *cross-flow microscreen algal system* which promotes the selective growth of the filamentous algae *Stigeoclonium* as a means of harvesting algae and removing residual traces of phosphate, has been described by Pretorius and Hensman (1984).

Water reclamation for potable purposes was pioneered by the National Institute for Water Research (NIWR) (Stander and van Vuuren, 1969) and the Windhoek water reclamation plant commissioned on 21 January 1969, became the first permanent plant in the world to reclaim sewage effluent for domestic use. Van Vuuren *et al.* (1985) have reviewed the use of diffused air flotation (DAF) in South Africa for effluent polishing purposes, and Vosloo *et al.* (1986) have described the combined use of air flotation and rapid gravity sand filtration as a single unit operation (DAFF). *Reclamation for flushing purposes* was a system adopted at Walvis Bay for periodically removing deposited material from very flat grade collector sewers (Rowe, 1960).

Chemical processes

The first recorded use of chemicals for sewage treatment relates to the treatment of settled sewage from 100 000 persons at the Zonderwater prisoner of war camp, by adding lime and alum prior to settlement and land disposal (De Vaal, 1945). The LFB process, developed by the NIWR, makes use of chemical flocculation, flotation and biological oxidation of nitrogen. This principle has been incorporated into prefabricated package plants suitable for small communities (WSAE, 1980).

Slaked lime was added to sewage prior to settlement at the Johannesburg Northern Works to raise the pH of the sewage to about 8,4 to overcome the loss of alkalinity due to double filtration, and the addition of iron sulphate for phosphate precipitation. This latter chemical was replaced with alum in 1987, to reduce the amount of free acid being added to the sewage. The "high lime" process designed to elevate secondary effluents to pH 11,0 has been used in both the Windhoek plant and the 4,5 Mℓ/d NIWR demonstration plant (Stander and Clayton, 1971). Ammonia was stripped from such effluents by air-blowing, but scaling problems led to the abandonment of this process in favour of biological nutrient removal techniques. Lime has also been used as a coagulant for humus tank effluent at the Germiston Rondebult Works, to improve effluent quality for compliance with statutory standards. Alum was substituted for lime after a period of a year (Van der Merwe, 1974/75). In 1981, underground water from the ERPM Mine containing 617 mg Fe/ℓ was bled into an outfall sewer leading to the Rondebult Works and this resulted in a final effluent containing about 0,7 mg P/ℓ (SAWB, 1983). Subsequent to 1 August 1985, the date on which effluents in certain specified areas had to comply with an effluent standard of 1 mg o-P/ℓ (max), many works have resorted to the use of ferric salts for the precipitation of iron phosphate.

The Vereeniging Leeukuil Works, which discharges effluent to the Leeukuilspruit, which in turn discharges to the Vaal Barrage, is required to meet an average total phosphorus standard of 0,15 mg P/ℓ, based on two-hourly samples. Provision has therefore been made to carry out additional chemical flocculation in a separate system with provision being made for the recycling of chemical sludge (WSAE, 1981).

Ocean outfalls

Sea outfalls were installed at Durban in 1894 (Kinmont, 1966) and in Cape Town (Greenpoint) about 1905 (Morris, 1971). In 1987 there were 67 or more authorised discharges to sea (Murray, 1987), totalling about 719 Mℓ/d (Odendaal and McGlashan, 1986). Ten of these discharges are via major submarine pipelines, two of which in the Durban region have been very extensively researched since 1962 (Kinmont, 1966). It is of interest to note the swing to high density polyethylene as a construction material in the Richards Bay area (WSAE, 1983) and at Mouille Point, Cape Town (Odendaal and McGlashan, 1986).

Acknowledgements

Thanks are due to the City Engineer and the Medical Officer of Health of Johannesburg, for permission to present this paper and to many people who helped the author gather information for inclusion in this paper.

References

ABBOTT, A.L. (1962) The Wynberg-Muizenberg Sewage Treatment Scheme. *J. Inst. Sew. Pur.* (3) 224-233.

ALEXANDER, W.V. and WOOD, A. (1986) Experimental investigation into the use of emergent plants to treat sewage in South Africa. *Proc. IAWPRC Specialist Seminar on Macrophytes,* Sao Paulo. August 1986.

BARNARD, J.J. (1962) The Rondebult sewage purification works: Its development and description. *J. Inst. Sew. Pur.* (4) 373-377.

BARNARD, J.L. (1974) Cut P and N without chemicals. *Wat. and Waste Eng.* 11(7) 33-36.

BARNARD, J.L. (1984) Activated primary tanks for phosphate removal. *Water SA* **10** 121-126.

BARNARD, J.L. (1986) Personal communication. PO Box 28734, Pretoria 0001, South Africa.

BASSETT, G.D. (1984/5) City Engineer's Department Annual Report. 73.

BEEKMAN, H.G.J. (1984/5) City Engineer's Department Annual Report. 80.

BENJAFIELD, F.E. (1960) Sewage disposal oxidation ponds. *Public Health* **60** 23-27.

BERGMAN, B.S. (1958) An improved circular sedimentation tank design. *J. Inst. Sew. Pur.* (1) 50-66.

BERGMAN, B.S. (1975) Brochure prepared for visit to Heidelberg Works by Inst. Wat. Poll. Cont. 22 March 1975.

BLACKBEARD, J. and EKAMA, G. (1984) Survey of activated sludge bulking and foaming in Southern Africa. *IMIESA* **9** 20-25.

BLERCH, H.C. and DE VILLIERS, H.A. (1971) Effluent management by judicious integration of various processes and utilisation of treatment plant beyond design capacity. *Wat. Poll. Con.* **70** 187-197.

BOLITHO, V.N. (1965) The economics of methods available to local authorities for the chemical and bacteriological improvements to purified sewage effluents. *J. Inst. Sew. Pur.* (3) 216-233.

BORLAND, J. (1987) Oxygenation of gravity sewers to control odours. Paper presented to Inst. Wat. Poll. Contr., Southern African Branch Conference, Port Elizabeth. May.

BRAND, J.G. (1981) The Cape Flats sewage treatment works. *Wat. Sew. and Effl.* (4) 41-45.

BRODISH, K.E.U. (1985) Removal of phosphates and nitrogen compounds from biological filter effluents. Report 58/1/85 published by the Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

Cape Town (1983) Brochure for IAWPRC Conf. Mar/Apl.

C C T. (various years). Cape Town City Engineer's Annual Report

D AND H WASTE MANAGEMENT CO. (1986) Beds installed privately by Darling and Hodgson Recycle Subsidiary.

DE LANGE, J.H. (1979) Tweestadium geaktiveerdeslykaanleg te Haartebeesfontein. *IMIESA* (Feb) 26-31.

DE VAAL, H.M. (1945) Sewage purification experience in South Africa. *J. Inst. Sew. Pur.* (2), 169-176.

DREWS, R.J.L.C. (1965) Field studies of large-scale maturation ponds with respect to their purification efficiency. *J. Inst. Sew. Pur. (3) 280-294.*

DURBAN (1973) Durban Corporation Brochure. Kwa Mashu Sewage Works.

DURBAN (1980) Durban Corporation Brochure. Central Works.

ENGELS, D. (1986) Personal communication. P.O. Box 35, Vereeniging, South Africa.

EKAMA, G., PITMAN, A.R., SMOLLEN, M. and MARAIS, G.v.R. (1984) *Theory, Design and Operation of Nutrient Removal Sludge Processes* (Chapter 8). Published by the Water Research Commission, P.O. Box 824, Pretoria 0001, South Africa.

ESTC (1947) Enclosed Sewage Treatment Co. SA (Pty) Ltd. (Defunct).

GARNER, J.H. (1930) Upward flow tanks. *The Assn. of Managers of Sew. Disp. Wks.* 224-228.

GERBER, A., SIMPKINS, M.J, WINTER, C.T. and SCHEEPERS, J.A. (1982) Biological nutrient removal from wastewater effluents: Performance evaluation of the Phoredox and UCT processes. CSIR Contract Report, C. Wat. **52** 1-188. PO Box 395, Pretoria 0001, South Africa.

HALL, E.J. (1957) Trends in the design of sewage purification works. *J. Inst. Sew. Pur.* (1) 51-60.

HALL, E.J. (1962) Sewage density variations in sedimentation tanks. *J. Inst. Sew. Pur.* (5) 469-477.

HALL. E.J. (1963) The design of the Northern Sewage Purification Works, Johannesburg. *J. Inst. Sew. Pur.* (6) 530-537.

HAMLIN, E.J (1949) Sewage disposal in subtropical countries with special reference to the Union of South Africa and Mauritius. *J. Inst. Sew. Pur.* (3) 235-256.

HAMLIN, E.J. and WILSON, H. (1951) The history, development, present, past and future trends of sewage disposal in South Africa. *J. Inst. Sew. Pur.* (3) 243-260.

HARRIS, D.V. and SKINNER, R.E. (1965) Sewerage and sewage purification in Pietermaritzburg. Paper presented to the Southern African Branch of the Inst. Sew. Pur. Conference, Durban. May 1965.

HARRIS, D.V. (1976) Pietermaritzburg's new sewage purification facilities. *Mun. Eng.* **7** 63-67.

HEYNIKE, J.J.C. (1950) The rapid gravity filtration of humus tank effluent without coagulants. *J. Inst. Sew. Pur.* (2) 135-143.

HEYNIKE, J.J.C. (1951) Operating experiences with a rotary comminutor. *J. Inst. Sew. Pur.* (4) 437-440.

HEYNIKE, J.J.C. (1954) Ventilation on a six-foot filter built into the ground. *Public Health* (June) 144-145.

HOWELL, H.O. (1983) Horizontal aerators in operation at Verwoerdburg sewage works. *IMIESA* **8** 85.

HOWES, A.M. (1986) Private communication. PO Box 680, Durban. South Africa.

JCEAR (Various years) Johannesburg City Engineer's Annual Report. PO Box 4323, Johannesburg 2000, South Africa.

JARSD, (Various years) Joint Annual Report on Sewage Disposal. City Engineer, PO Box 4323, Johannesburg 2000, South Africa.

JENKINS, D., NEETHLING, J.B., BODE, H. and RICHARD, M.G. (1982) The use of chlorination for control of activated sludge bulking. In: *Bulking of Activated Sludge - Preventative and Remedial Methods.* (Editors) Chambers, B. and Tomlinson, E.J. Ellis Horwood Ltd.

KEAY, G.F.P. (1979) Northern Sewage Works. *IMIESA* **4** 17-21.

KEAY, G.F.P. (1984) Practical design considerations, Chapter 10 - In: *Theory, Design and Operation of Nutrient Removal Activated Sludge Processes.* Published by the Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

KERDACHI, D.A. and ROBERTS, M.R. (1980) The ability of the extended aeration activated sludge process to remove phosphorus to less than 0,1 mg P/ℓ in a simple surface aerated rectangular reactor. IWPC (SA Branch) Conference, Pretoria. 2 to 6 June.

KERDACHI, D.A. and ROBERTS, M.R. (1983) Optimal sizing of basin units in activated sludge. (Unpublished). Copies from SS and O, PO Box 846, Pietermaritzburg 3200, South Africa.

KERDACHI, D.A. and ROBERTS, M.R. (1985) Phosphate removal in Pinetown's Umhlatuzana Plant. *Acinetobacter* and ferrous ions in anaerobic zones. *Wat. Sci. Tech.* **17** 301-322.

KING, P.B. (1982) Borchards Quarry wastewater treatment works. *Wat. Sew. and Effl.* (8) 49-51.

KINMONT, A. (1966) Sewage disposal problems in Durban. *J. Inst. Sew. Pur.* (3) 235-248.

KOLBE, F.F. (1975) Brochure on Kempton Park Works. SS and O, PO Box 784148, Sandton 2146, South Africa.

KOLBE, F.F. (1986) Personal Communication. SS and O, PO Box 784148, Sandton 2146, South Africa.

LETCHER, C.R. (1982) Durban's wastewater treatment works. *IMIESA* **7** 27-30.

LOUW, A.S. and BASSON, H.J. (1983) Extensions to Vlakplaats water pollution control works, Boksburg. *Wat. Sew. Effl.* (Dec) 11-15.

McLACHLAN, J.A. (1936) The settlement and rising of activated sludge. *J. Inst. Sew. Pur.* (1) 49-74.

MORRIS, S.S. (1971) Water and waste management in the Cape Town metropolitan area. *Wat. Poll. Control* **70** 127-129.

MURRAY, K.A. (1987) *Wastewater Treatment and Pollution Control.* 117. Published by the Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

NICHOLLS, H.A. (1977) Modification of extended aeration plants in Johannesburg, South Africa. *Prog. Wat. Tech.* **8** 639-652.

NICHOLLS, H.A., PITMAN, A.R. and OSBORN, D.W. (1984) The readily biodegradable fraction of sewage. *Wat. Sci. Tech.* **71** 73-87.

NICOLLE, N.P. (1955) Humus tank performance, micro-straining and sand filtration. *J. Inst. Sew. Pur.* (1) 19-23.

NICOLLE, N.P. (1957) Operational aspects of control of rapid gravity filters. *J. Inst. Sew. Pur.* (3) 273-275.

OBERHOLSTER, G. (1983) South African practice in land disposal of sludge. *Wat. Sci. Tech.* **15** 151-155.

ODENDAAL, P.E. and McGLASHAN, J.E. (1986) Coastal discharges in South Africa with particular reference to the Durban experience. *Wat. Poll. Con.* **85** 189-199.

OSBORN, D.W. (1961) Some experiments with the activated sludge process in Johannesburg. *J. Inst. Sew. Pur.* (3) 227-237.

OSBORN, D.W. (1965) Operating experience with double filtration in Johannesburg. *J. Inst. Sew. Pur.* (3) 272-281.

OSBORN, D.W. (1979) Evolution of wastewater processes in Johannesburg, South Africa. *WPCF* **51** 467-483.

OSBORN, D.W., LÖTTER, L.H. and NICHOLLS, H.A. (1986) Enhancement of biological phosphate removal by altering process feed composition. WRC Report 137/1/86, Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

PAEPCKE, B.H. (1983) Performance and operational aspects of biological phosphorus removal plants in South Africa. *Wat. Sci. Tech.* **15** 219-223.

PASVEER, A.A. (1959) A contribution to the development in activated sludge treatment. *J. Inst. Sew. Pur.* (4) 436-465.

PECC (1978) Port Elizabeth City Council brochure: Fishwater Flats reclamation works.

PITMAN, A.R. (1985) Settling of nutrient removal sludges. *Wat. Sci. Tech.* **17** 493-504.

POLLOCK, J.J. (1934/35) Local use of compressed gas for vehicle operators. Johannesburg City Engineer's Annual Report, PO Box 4323, Johannesburg 2000. 7-12.

PRETORIUS, W.A. and HENSMAN, L.C. (1984) The selective culture of easily harvestable algae using crossflow microscreening. *Wat. Sci. Tech.* **17** 791-802.

PRETORIUS, W.A. and LAUBSCHER, C.J.P. (1987) Control of biological scum in activated sludge plants by means of selective flotation. *Wat. Sci. Tech* **19** 1003-1011.

PRÜSS DIGESTERS (1947) Brochure issued by Enclosed Sewage Treatment Co, SA (Pty) Ltd, Johannesburg (now defunct).

ROWE, A.A. (1960) Sewerage and sewage disposal at Walvis Bay. *Public Health* **60** 27-37.

SAMSON, J. (1950) Cleaning aeration plates in the diffuser air system of activated sludge treatment of sewage. *J. Inst. Sew. Pur.* (2) 132-134.

SAWB (1983) Fosfaatverwydering met suurmynwater. *SA Waterbulletin,* Aug. 18-21. Published by Water Research Commission. PO Box 824, Pretoria 0001, South Africa.

SHORTEN, J.R. (1986) A history of the City Engineer's Department, Johannesburg, 1886 - 1986. *IMIESA* **11** 15-21.

SIEBRITZ, I.P., EKAMA, G.A. and MARAIS, G.v.R. (1983) A parametric model for biological excess phosphorus removal. *Wat. Sci. Tech.* **15** 127-152.

SKINNER, D.H.H. (1986) Personal communication. SS and O, PO Box 784148, Sandton 2146, South Africa.

SLIM, J. (1986) Some developments in the water industry in South Africa. Presented at IWPC Annual Conference, Birmingham, England. 8-11 September.

STANDER, G.J. and VAN VUUREN, L.R.J. (1969) The reclamation of potable water from wastewater. *JWPCF* **42** 355-367.

STANDER, G.J. and CLAYTON, A.J. (1971) Planning and construction of wastewater reclamation schemes as an integral part of water supply. *Wat. Poll. Control.* **70** 228-234.

TOERIEN, D.F. and WALMSLEY, R.D. (1979) The chemical composition of the upper Hennops River and its implications on water quality of Rietvlei Dam. *Water SA* **5** 77-79.

TREVELYAN, W.E. (1948) Denitrification in sewage sludge. M.Sc. Thesis, GKT 7715 705, University of South Africa, Pretoria, South Africa.

TRIM, B.C. (1982) The Johannesburg wastewater treatment system. *IMIESA* **7** 17-19.

TRIM, B.C. and McGLASHAN, J.E. (1985) Sludge stabilisation and disinfection by means of auto-thermal aerobic digesters with oxygen. *Wat. Sci. Tech.* **17** 563-573.

VAN DER MERWE, P.H. (1974/75) Annual Report of Chief Chemist. City Engineer's Department, PO Box 145, Germiston 1400, South Africa.

VAN DER MERWE, P.H. (1987) Personal Communication. PO Box 145, Germiston 1400, South Africa.

VAN ECK, H. and SIMPSON, D.E. (1966) The anaerobic pond system. *J. Inst. Sew. Pur.* (3) 251-260.

VAN NIEKERK, A.M. (1980) Thesis: Unslaked lime treatment of dewatered sludges. University of the Witwatersrand, Johannesburg, South Africa.

VAN VUUREN, L.S.R., OFFRINGA, G. and WILLIAMS, P.G (1985) Development and application of DAF technology in South Africa. *Inst. Wat. Poll. Contr. Year Book and Buyers Guide* 1985/86. 75-89.

VENTER, S.L.V., HALLIDAY, J. and PITMAN, A.R. (1978) Optimisation of the Johannesburg Olifantsvlei extended aeration plant for phosphorus removal. *Prog. Wat. Tech.* **10** 279-292.

VOSLOO, P.B.B. and O'REILLY, T.P. (1945) The effect of artificial ventilation on the treatment of sewage by biological filters. *J. Inst. Sew. Pur.* (2) 160-163.

VOSLOO, P.B., WILLIAMS, P.G. and RADEMAN (1986) Pilot and full-scale investigations on the use of combined dissolved air flotation (DAFF) for water treatment. *J. Inst. Wat. Poll. Cont.* **85** 114-121.

VTC (1985) Vereeniging Town Council. Official brochure on opening of Leeukuil water reclamation works.

WAKEFIELD, R.W. and SLIM, J.A. (1987) The practical application of various techniques to control sludge bulking. IWPC Conference, Port Elizabeth, South Africa. May 1987.

WARNER, A.P.C. (1985) Phosphate removal without chemical addition. *Wat. Sew. and Effl.* (June) 35-37.

WESTHOF, J.H.W. (1960) The performance of six-feet deep biological filters built below ground level. *J. Inst. Sew. Pur.* (1) 90-91.

WHITE, E.G. (1953) Attempts to improve the Delta Works effluent in order to avoid stream pollution. *J. Inst. Sew. Pur.* (1) 61-67.

WRC (1964) Water Pollution Research. Ministry of Technology HMSO. 88-91.

WRC (1984) Autothermal aerobic digestion using oxygen. Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

WRC (1986) The pasteurisation of sludge. Water Research Commission Report No 86/1/6/86. PO Box 824, Pretoria 0001, South Africa.

WSAE (1980) Skid mounted sewage treatment plant 1 71-73.

WSAE (1981) Food from thought. *Wat. Sew. and Effl.* **2** 47-50.

WSAE (1981) Leeukuil sewage purification works, Vereeniging. *Wat. Sew. and Effl.* (5) 29-35.

WSAE (1983) Submarine effluent disposal system at Richards Bay. *Wat. Sew. and Effl.* **4** 5-8.

WSAE (1985) Review article in *Water, Sewage and Effluent* **6** 28-30.