INTERMITTENT OPERATION OF SLOW SAND FILTERS FOR ARTIFICIAL RECHARGE OF GROUNDWATER *

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General Subject

" ARTIFICIAL FILTRATION - RECHARGE OF GROUNDWATER SUPPLIES "

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At the Ruhr Valley Waterworks slow sand filters constitute a one stage purification step of surface water, and serve at the same time as an infiltration surface for the artificial recharge of groundwater.

Figure 1 gives a simplified scheme of the purification process of a mainly biological slow sand filter. The chief disadvantages of this form of water processing are that the filter surface gradually, or sometimes quickly, becomes clogged by the suspended matter introduced by the river water and that there is a decrease of oxygen content and an increase of carbonic acid following the biogenic degradation in the water as it drains through. Efforts to improve the method therefore centre mainly on lengthening the filter running period and increasing the oxygen supply, but at the same time intensifying the degradation of the organic substances.

Figure 2 shows the principle, which has been in use at the Dortmund Municipal Waterworks for the past 15 years, of pre-purification through prefilters, which are also biologically active and are filled with coarse filter material of about 5 - 12 mm in diameter. They operate as room filters, and the filter gravel has to be removed completely and cleaned every four or five years. The chief advantages of the process are:

(1) The slow sand filters which serve as infiltration basins receive water which is practically free of suspended matter.

(2) The change in the O_2/CO_2 ratio, which has already taken place in the prefilter as a result of biological degradation, is counterbalanced by aeration at the entrance to the main filter.

(3) The use of two biological filter stages means that this method of water processing generally achieves a higher degree of purification.

Figure 3 contains some measurements relating to the system. The water-bearing strata is 4-5 metres deep and is covered by a layer of river loam 0.5-2 metres thick. The river gravel is usually extremely permeable. Permeability coefficients range from about 10^{-3} to 10^{-2} m/sec. The lower limit of the water-bearing strata consists of slaty rock, at a depth of about 7 metres. The gravel sometimes contains clay layers and very frequently deposits of iron and manganese oxides. Therefore, it is essential for the infiltrated water to stay aerobic while passing through the water-bearing strata.

During pumping, the area of depression of the groundwater usually reaches such a low level, that groundwater does not dam back into the filter basin. This is advantageous for filtering, but it also means that the bank-filtrate approaching from the river side, which often constitutes 40% of the groundwater which has been caught, is difficult to force back.

As Figure 4 clearly shows, the oxygen consumption of the river water, especially at low water, occasionally approaches its actual oxygen content; therefore, bank infiltration must be expected to lead to anaerobic conditions, at least temporarily. It is therefore necessary to introduce as much oxygen as possible into the substratum with the artificially filtrated water, in order to bind the iron and manganese. Excessive algal growth on the prefilter basins presents another problem. The mats of algae on the prefilter basins not only quickly clog the filter surface, but they also cause the filter space below to cease to participate in trapping suspended solids (Figure 5).

Thus the filter material is not fully utilized until the next time the filter is cleaned.
Moreover, extensive algal growth also forms on the main filters, that is, the infiltration basins, unless steps are taken to prevent it.

In order to increase the oxygen content in the groundwater and prevent excessive algal formation, the recharge plants have been operated intermittently for the last 10 years. Figure 6 shows a Prefilter and Main Filter System of this kind at the Groundwater Pilot Plant of the Dortmund Municipal Waterworks. The raw water flows continuously into the prefilter. When the water in the prefilter has reached a sufficiently high level, the drain to the main filter is opened. The main filter at the pilot plant is therefore fed at rhythmic intervals (every few hours)[1].

Figure 7 gives some chemical values in a system of this kind. A comparison of the consumption of permanganate shows that biological degradation is practically the same in the submerged filter and in the intermittent system. In spite of this, the oxygen content in the intermittent system is nearly at saturation point. Intensive aeration of the filter material also causes a decrease in the content of carbonic acid.

Figure 8 gives the oxygen content of the water as it leaves the prefilter basin, as recorded with a stylus.[2] Whereas the submerged prefilter shows a day-night rhythm dictated by the assimilation by the algae, the intermittently emptied prefilter shows shorter periods at a higher level.

Figure 9 records the oxygen changes in a submerged operated filtration basin at a depth of 2.20 m. The first two days were sunny, the next two cloudy. As it can be seen, algal growth causes oxygen variations in the filtrate ranging from 11 to 0.5 mg/1 O_2 within 12 hours.

In Figure 10, graph I gives the oxygen content in a filtration basin without a prefilter in the course of a day: it reveals the usual day-night pattern. Graph II shows how the daily maximum of a submerged prefilter can counterbalance the lowest values of the main filter. Graph III shows the course of an intermittently operated Prefilter and Main Filter System. The O_2 content is practically at saturation point.

As higher plant species can also thrive in an intermittently operated filter, management must ensure that surrounding meadows are mown before the seeds disperse.

In order to test intermittently operated filtration under difficult conditions, a small pilot plant was set up beside a polluted creek. The creek was polluted with both domestic and industrial effluent-

Degradation of the organic substance - the consumption of permanganate in the raw water was in the region of 30 mg/l $KMnO_4$ - was clearly better in the intermittently operated system. Figure 11 shows the concentration changes in the nitrogen compounds. The nitrate content, sharply increased in comparison with that in the submerged filter, proves that considerably more oxygen can be made available by the intermittent procedure. Although an algal population introduced additional oxygen into the submerged filter, the excess oxygen in the intermittent system was calculated, simply from nitrate formation and measured O_2 decrease, at nearly 30 mg/l O_2.

The submerged and the intermittently operated systems were also tested with specific pollution by petrol[3]. 200 mg/l high-grade petrol was added to the Ruhr water. Figure 12 shows that the CBS content dropped practically the same amount in both systems. In the case of the submerged operation, there was somewhat more volatilisation because not all the petrol immediately disolved.

Figure 13 shows the changes in bacterial content in the course of the experiment. The germ counts in the outflow of the intermittently operated main filter were considerably lower than in the submerged control basin. When there is no oil pollution, the germ count in the intermittently operated filter system occasionally rises to twice that in the submerged control basin.

The oxygen content (Figure 14) in the effluent from the intermittent system was in the region of 4 mg/l O_2, whereas it fell to zero in the submerged filter. Thus the lack of oxygen restricted further degradation there.

As there was sufficient oxygen in the intermittent system, the

CO_2 content (Figure 15) was nearly four times as high as in the effluent from the submerged filter. Undoubtedly the production of CO_2 is much higher because when the filter is intensively aerated, much more of the carbon dioxide is directly exposed to the air.

Figure 16 shows clearly that the nitrate content in the intermittent system - although 4 mg/l O_2 was still present - fell to zero. Here nitrogen was therefore the restricting factor in the further degradation of hydrocarbons.

These pollution experiments proved the advantages of the intermittent system for the biological degradation of organic matter. In fact, we have not yet been able, for technical reasons, to realize a regular intermittent working of the prefilters, but our infiltration basins are operated in a 24 or 48 hour cycle.

Figure 17 shows the recharge plant at Westhofen belonging to the Dortmund Municipal Waterworks. The prefilters are quadratic and in parallel operation. The long main filter basins are fed in turn every 24 hours, so that water is fed into only one of each pair of basins. As intermittently operated basins are only completely stored over when there is a higher effluent flow-in, the filter inlets, which used to be situated on the small side, have been moved to the long side in the new basins, in order to filter as much water as possible each time. There is also space available on this long side for building aeration cascades.[4] (Figure 18).

In the course of intermittent filtration, small quantities of algae are formed only during fairly long rainy periods, which prevent the filter surface from drying up during its 24 hour period of non-activity; the algae, however, die off during periods of good weather. The mats of algae crack open, and the water is able to seep through the exposed filter surface again, unhampered. Since the Dortmund Municipal Waterworks have changed to intermittent filtration, no filter has had to be put out of operation unexpectedly and cleaned because of excessive algal growth.

Figure 19 plots the course of the temperature on dry sand surface in sunny weather. The rise in temperature is, of course, important in drying out the algae.

Figure 20 gives a somewhat idealized plan of the purification process of a prefilter and main filter system. Only the prefilter becomes clogged with suspended matter and algae that have floated in. The inserted aeration ejects the CO_2 that has formed and restores the O_2 content to saturation point. Clogging of the main filter can hardly be observed. Before we introduced pre-filtration, the filtration basins in our water-winning territory infiltrated about 100-120 m^3 of raw water per square meter of filter surface per running period. Since submerged prefiltration has been introduced, capacity has risen to 400-500 m^3 per square meter of filter surface. With intermittent operation, more than 1000 m^3 per square meter of filter surface can be filtered before the basin needs cleaning.

Figure 21 shows an attempt to ascertain and specify the costs of prefiltration[5]. Naturally, the longer the filter, the greater the maintenance costs will be and in particular the construction costs of a gravel filter. The costs of manpower for washing the gravel are also considerable. So the running periods of the gravel filter have to be lengthened to achieve an optimal cost situation.

Looking at the total costs of prefiltration and infiltration (Figure 22), it can be seen that a definite saving can be made by inserting the gravel filter. In other words, not only does one achieve water of a better quality, but at the same time one enjoys certain financial advantages. In this figure, calculations were based on an average suspended matter content of 8.3 ppm. The best prefilter for our purposes, from a financial point of view, is about 40-50 m long. The existing filter basins, however, are 50-70 m long. They have a reserve capacity, and can be operated for a correspondingly longer time.

If the suspended matter content is higher (Figure 23), the insertion of the prefilters will produce even greater savings. The numbers of the ordinates represent amounts in German pfennings; these do not include land requirements and catchment pipes and wells.

Slow sand filters can also be intermittently operated under other climatic conditions. At the water purification plant at Bujumbura in Africa, for instance, intermittently working slow sand filters are being successfully used, not to recharge groundwater artificially, but to provide drinking water directly from the water of Lake Tanganyika.

Waterwork operations are being disrupted more and more frequently by mass algal growth. The results, as we know, can vary from simply shortening the filtration period to excreting maloderous and unpalatable substances, and even to the threat of toxic substances being formed.

As our rivers and lakes become increasingly polluted with growth-promoting substances, more importance will be attached to methods of controlling algae.

Algae need light, nutrients and water in order to grow. Intermittent filtration deprives them of one of these vital requirements: water - paradoxical though it may seem for a water purification plant.

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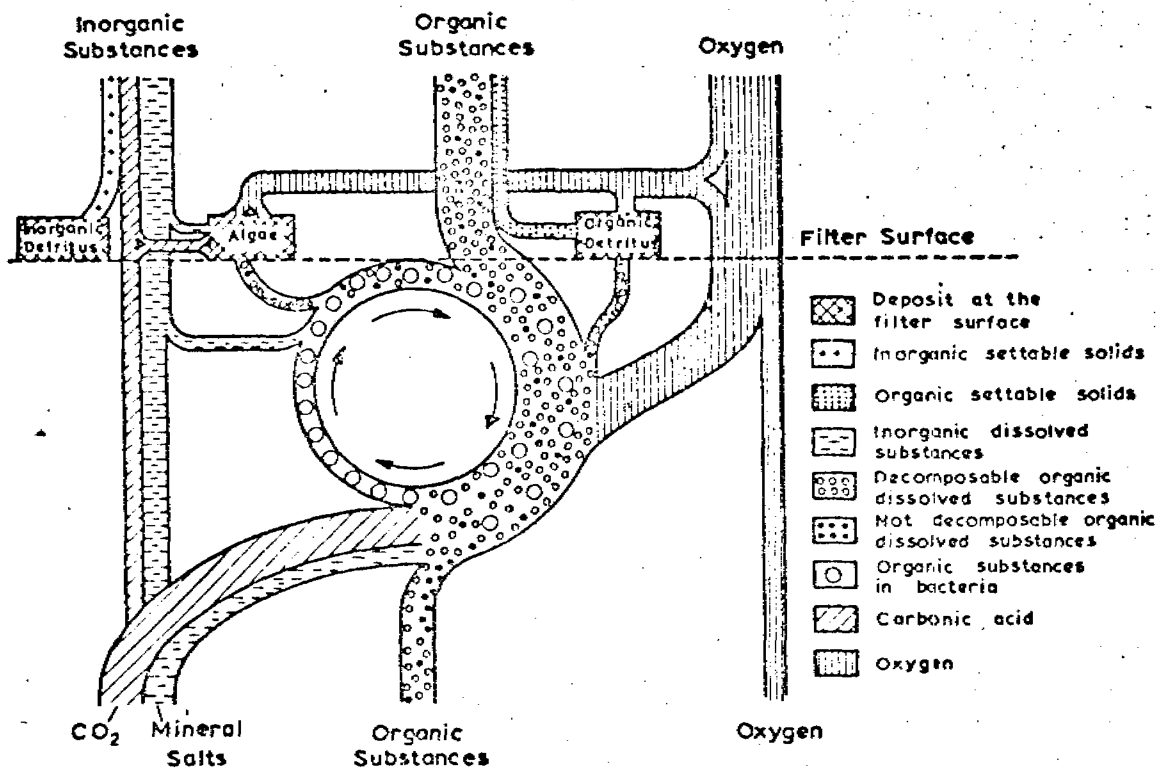

Fig. 1 SCHEME OF THE PURIFICATION EFFECT OF A SLOW SAND FILTER

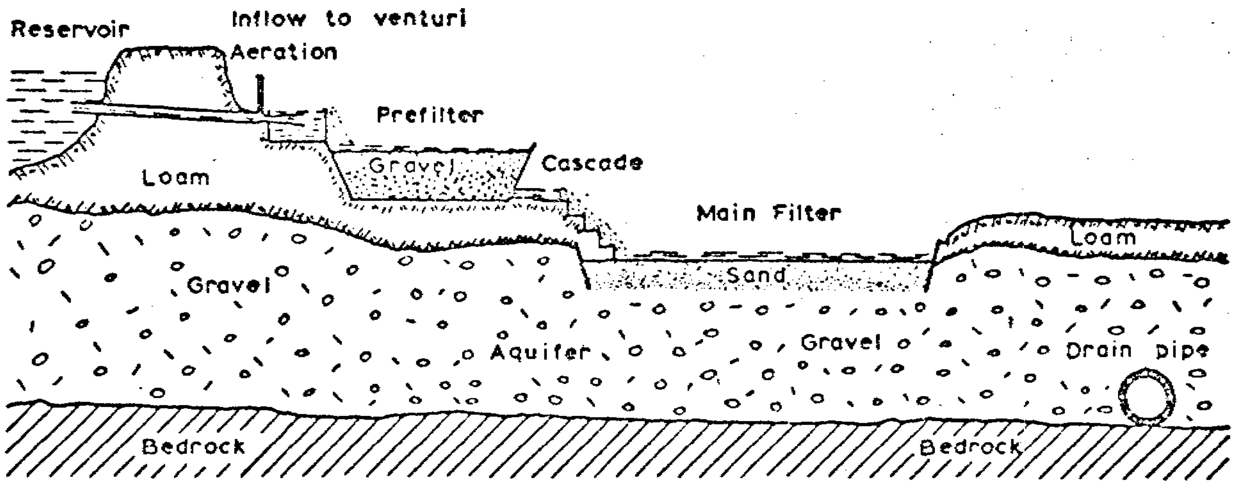

Fig. 2 SCHEMA OF A PLANT WITH PREFILTER BASIN FOR THE ARTIFICIAL RECHARGE OF GROUNDWATER

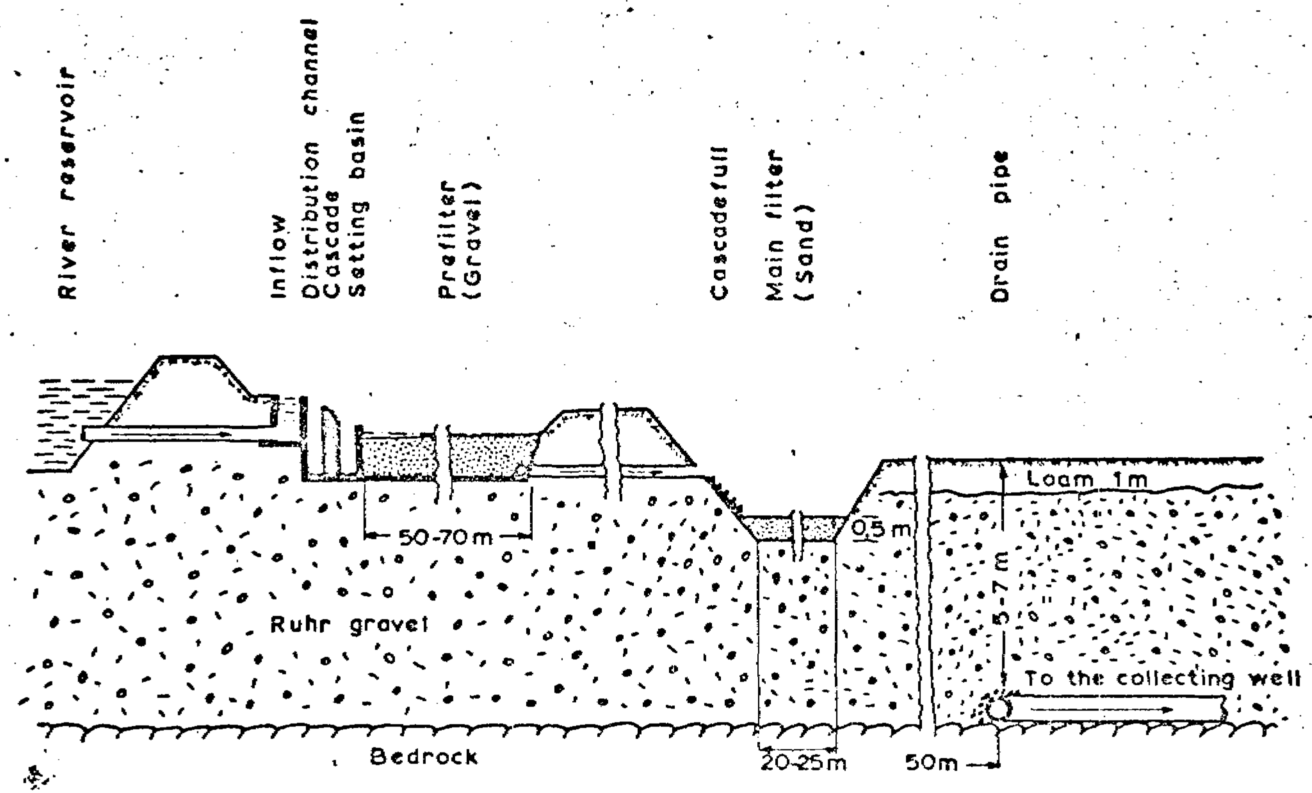

Fig. 3 SCHEME OF ARTIFICIAL GROUNDWATER RECHARGE

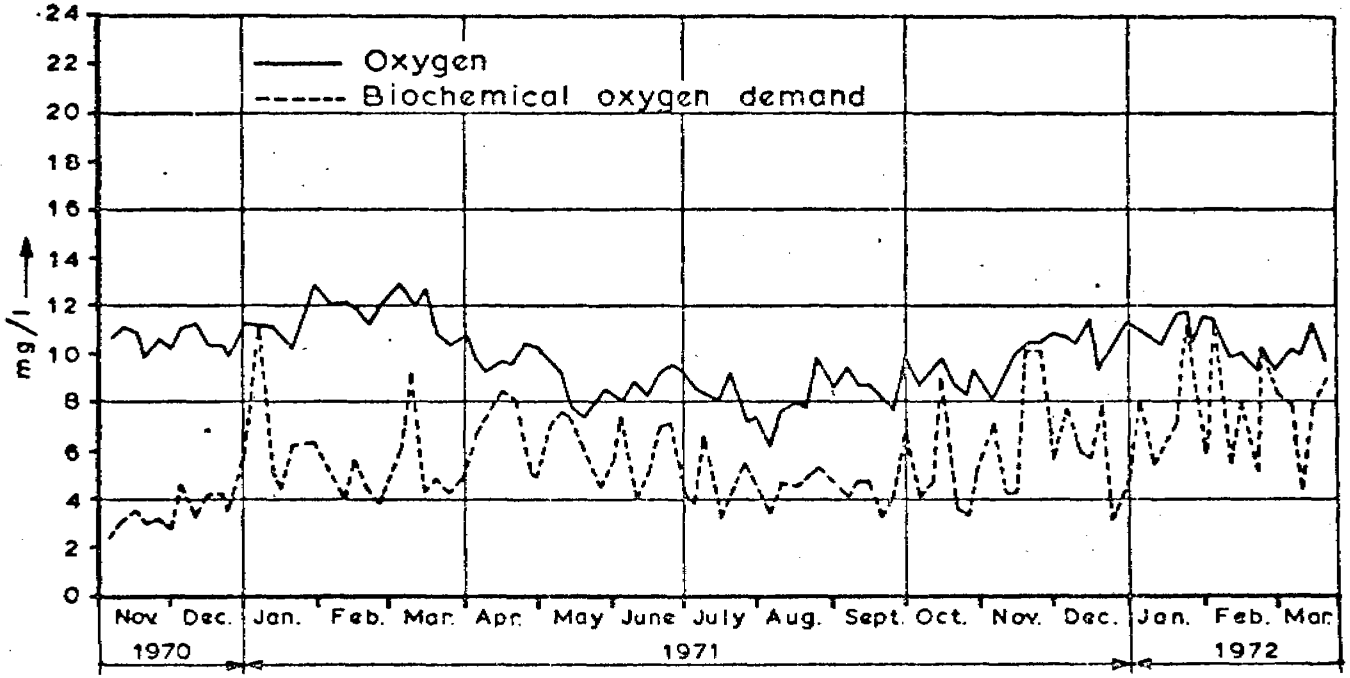

Fig. 4 OXYGEN CONTENT AND BIOCHEMICAL OXYGEN DEMAND IN THE RUHRWATER

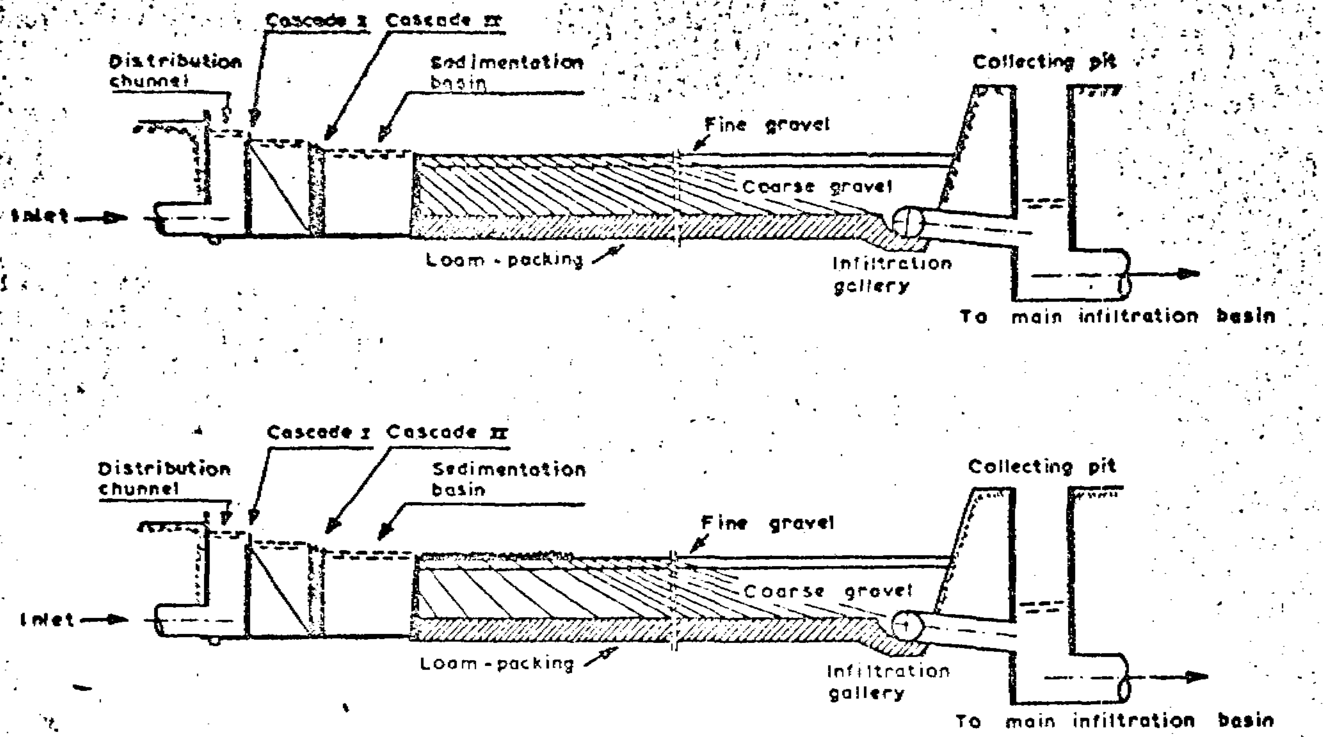

Fig. 5 PRIMARY FILTER AT WANDHOFEN CROSS SECTION

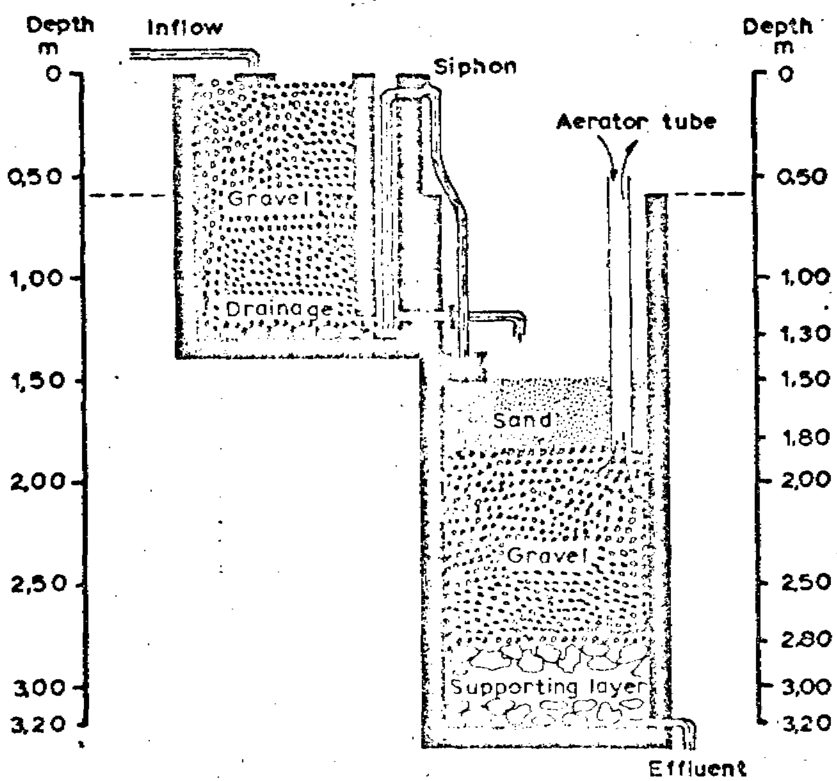

Fig. 6 PRIMARY AND MAIN FILTER FOR INTERMITTENT AERATION

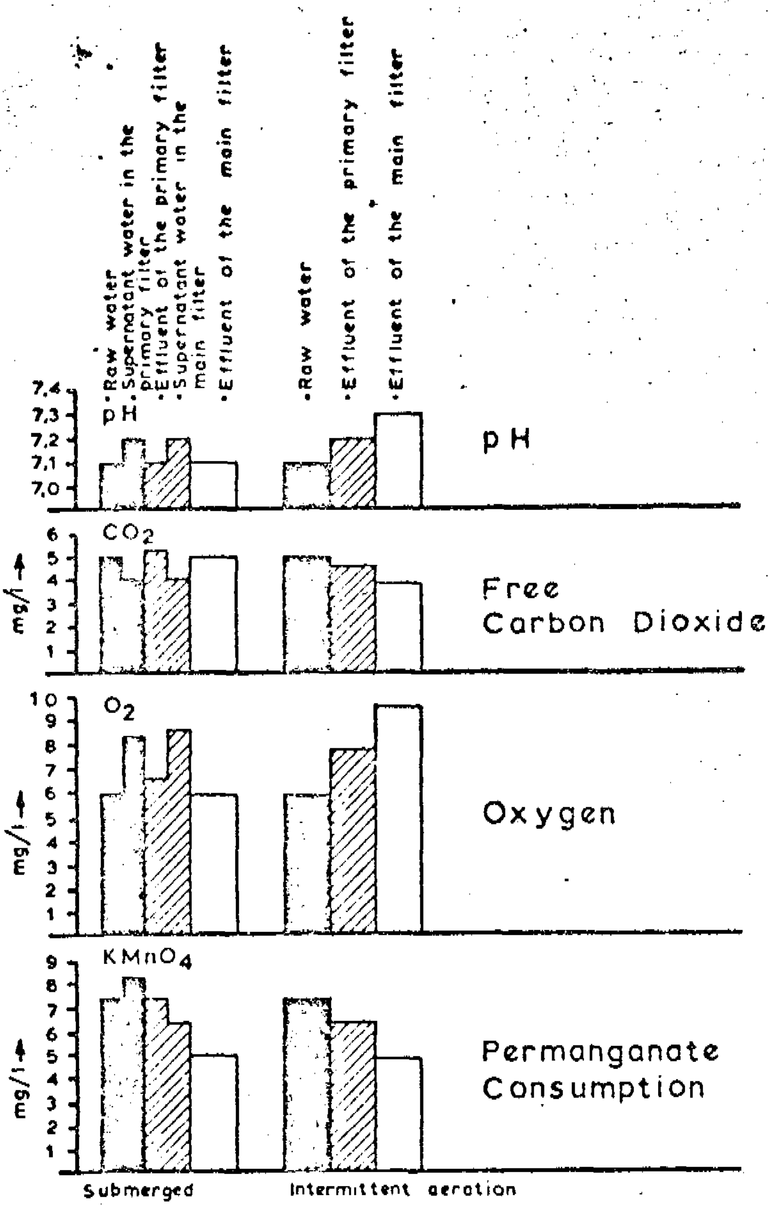

Fig. 7 ALTERATION OF VARIOUS CHEMICAL VALUES DURING THE INFILTRATION WITH PRIMARY FILTERS

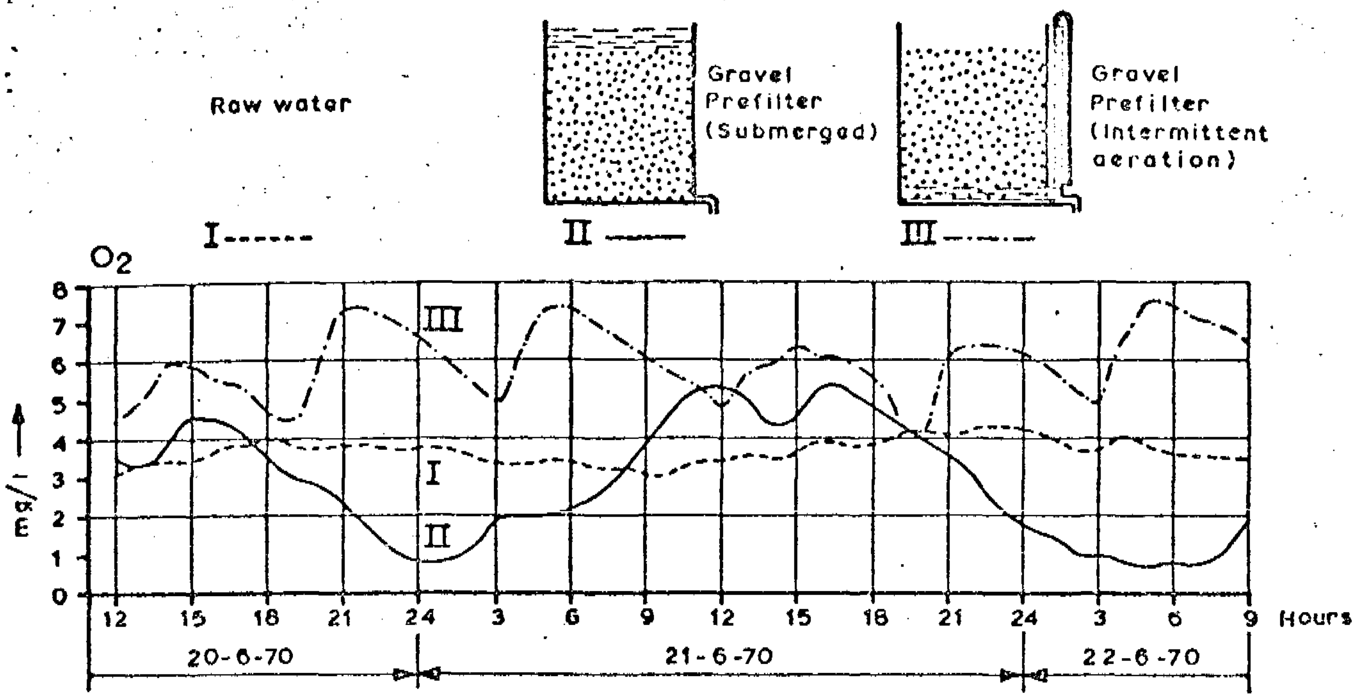

Fig. 8 OXYGEN CONTENT IN EFFLUENT FROM GRAVEL PREFILTERS

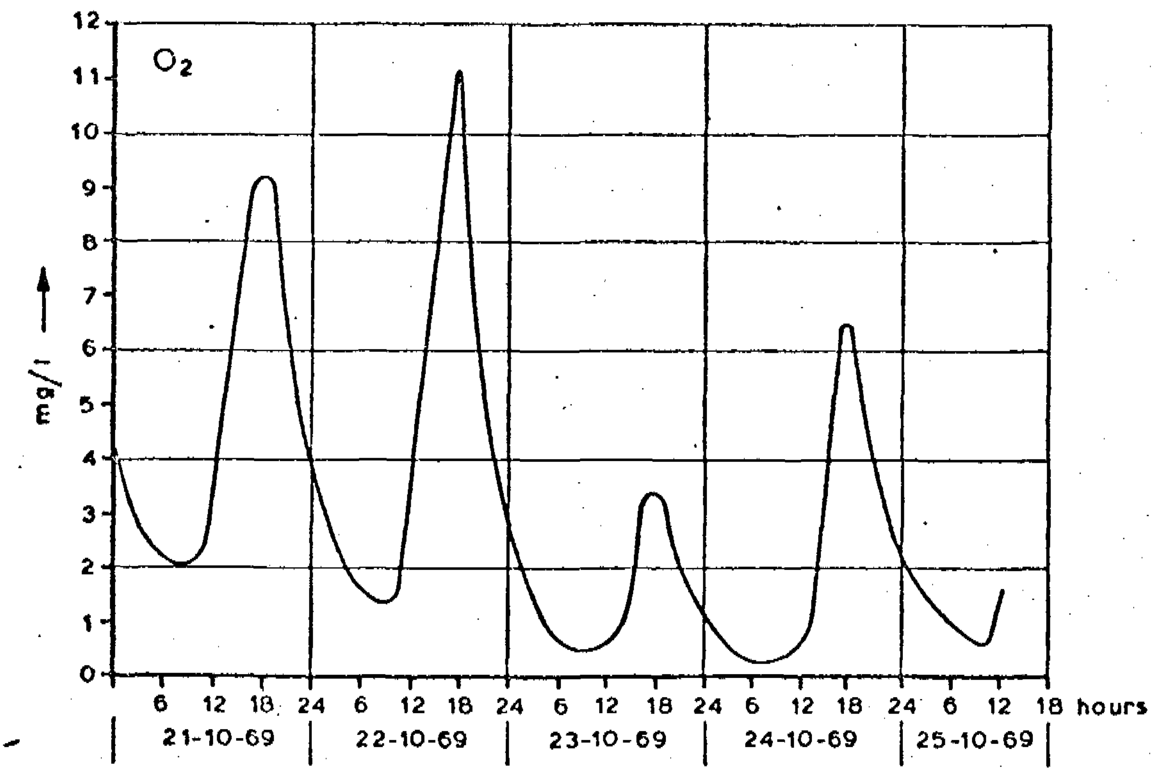

Fig. 9 VARIATION OF OXYGEN IN OUTFLOW OF A SLOW SAND FILTER

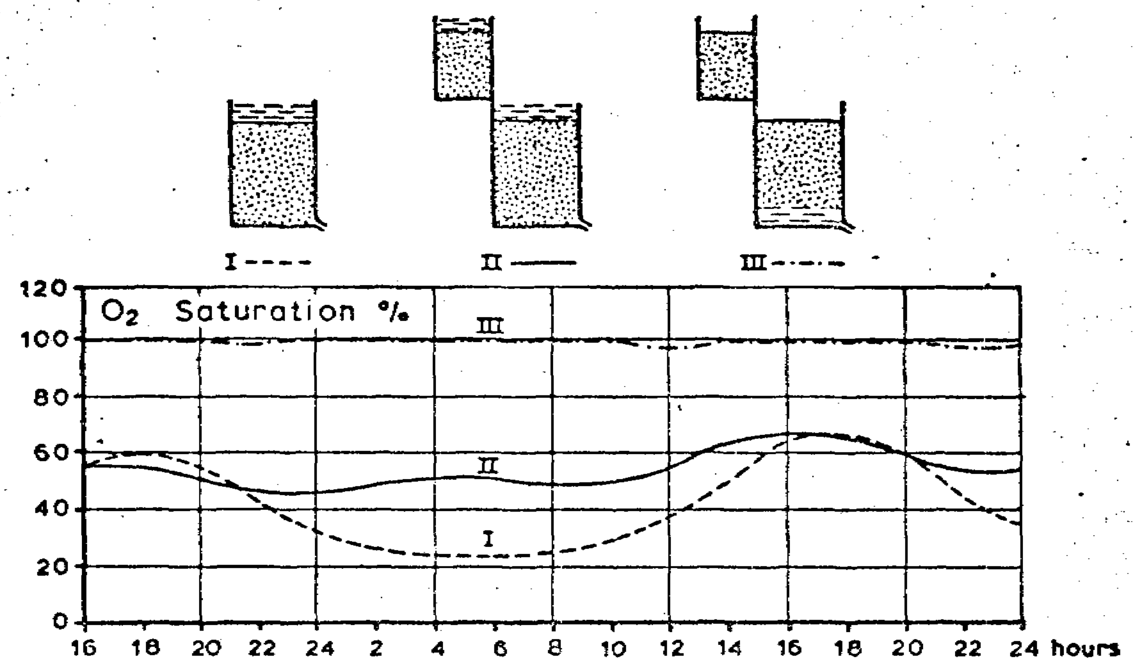

Fig.10 OXYGEN CONCENTRATION IN THE OUTFLOW OF SLOW SAND FILTERS

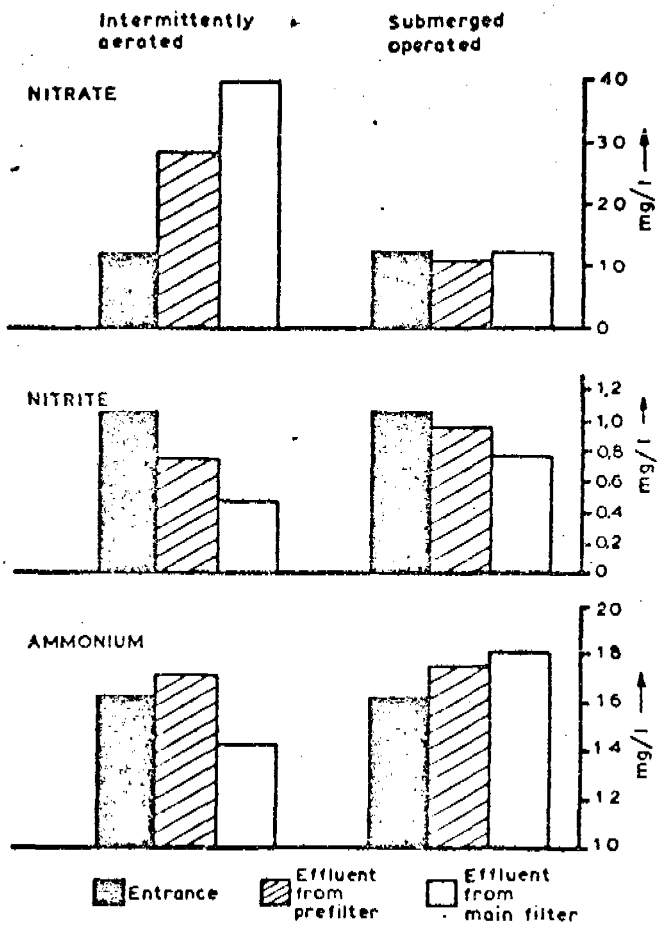

Fig. 11 CHANGES IN N COMPOUNDS CONTENT IN THE WATER BAARBACH PILOT PLANT

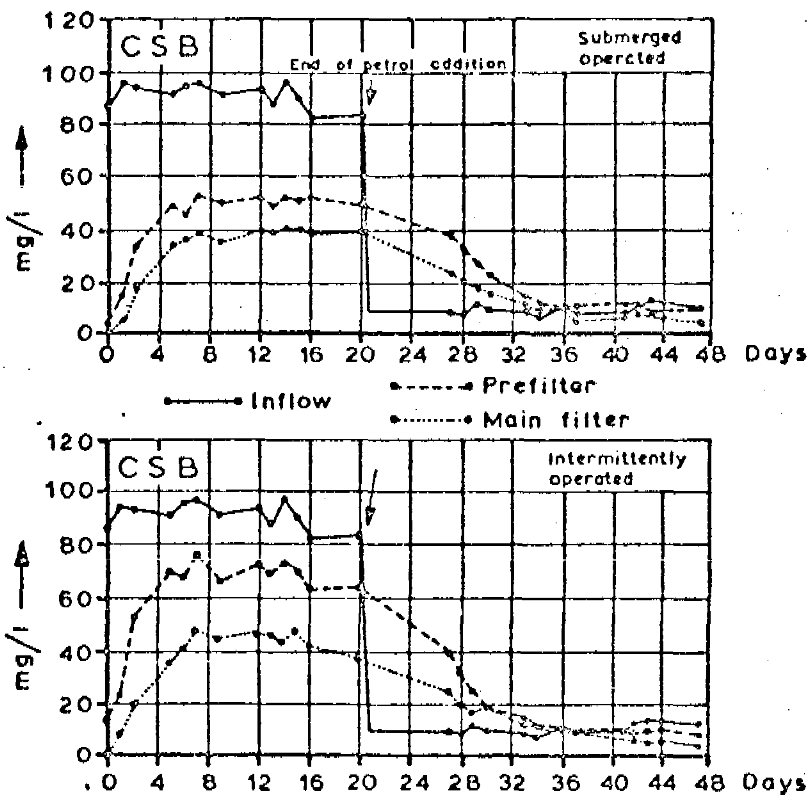

Fig. 12 ADDITION OF PETROL TO SLOW SAND FILTERS

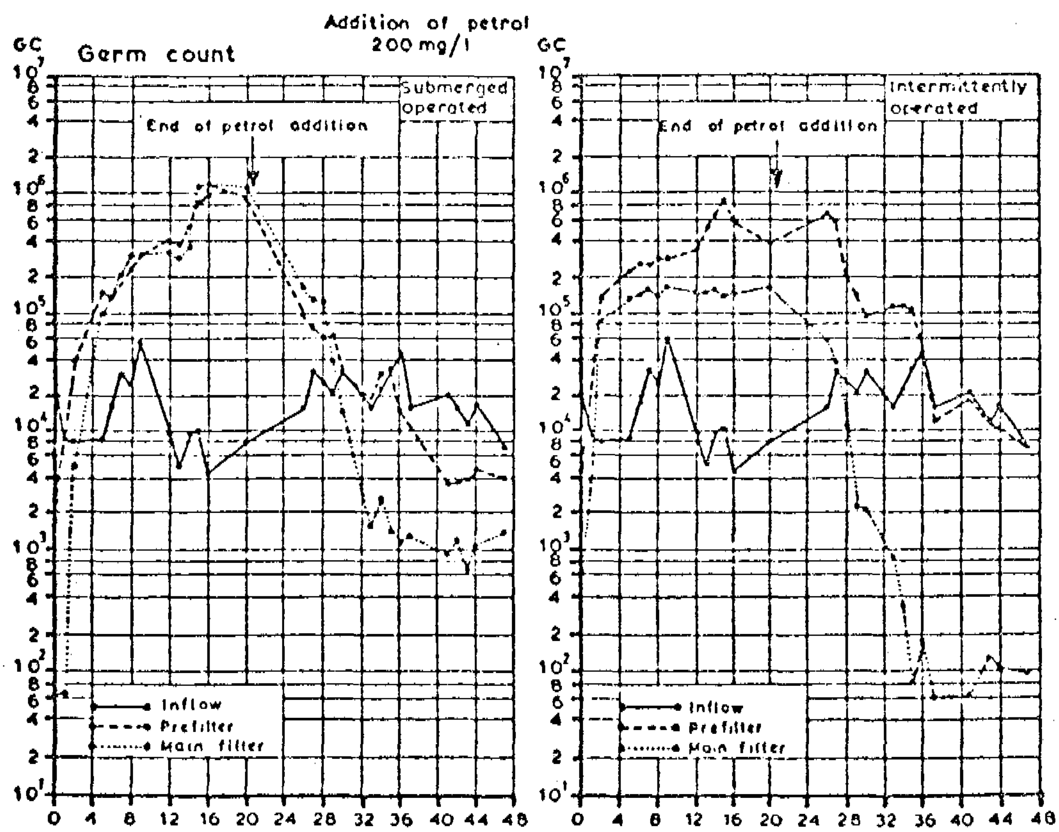

Fig.13 ADDITION OF PETROL TO SLOW SAND FILTERS

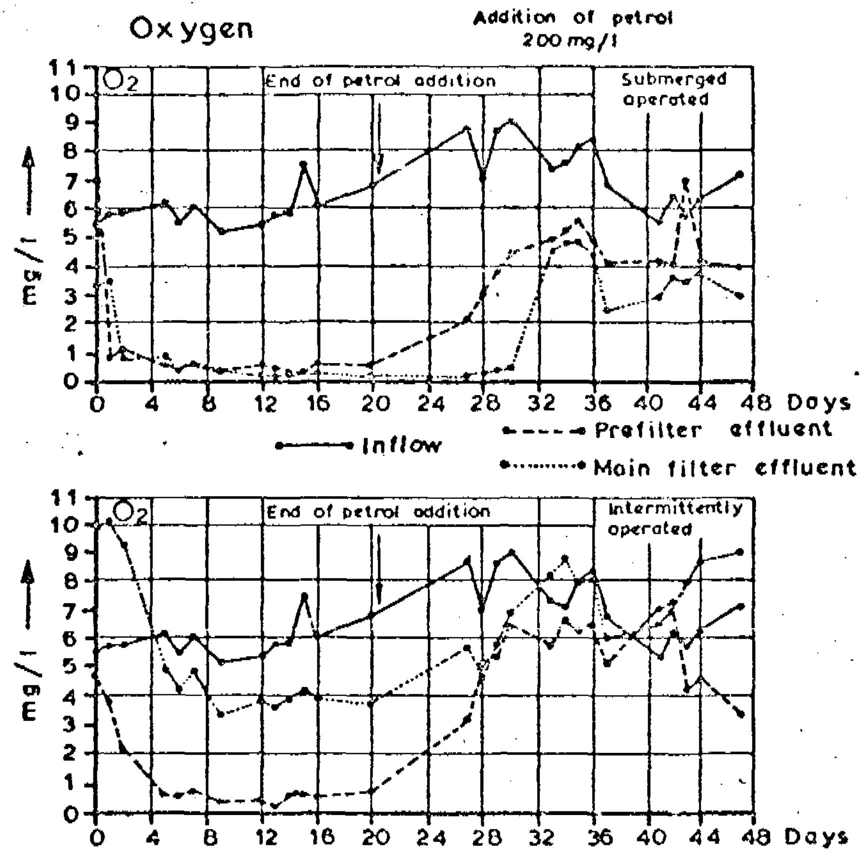

Fig.14 ADDITION OF PETROL TO SLOW SAND FILTERS

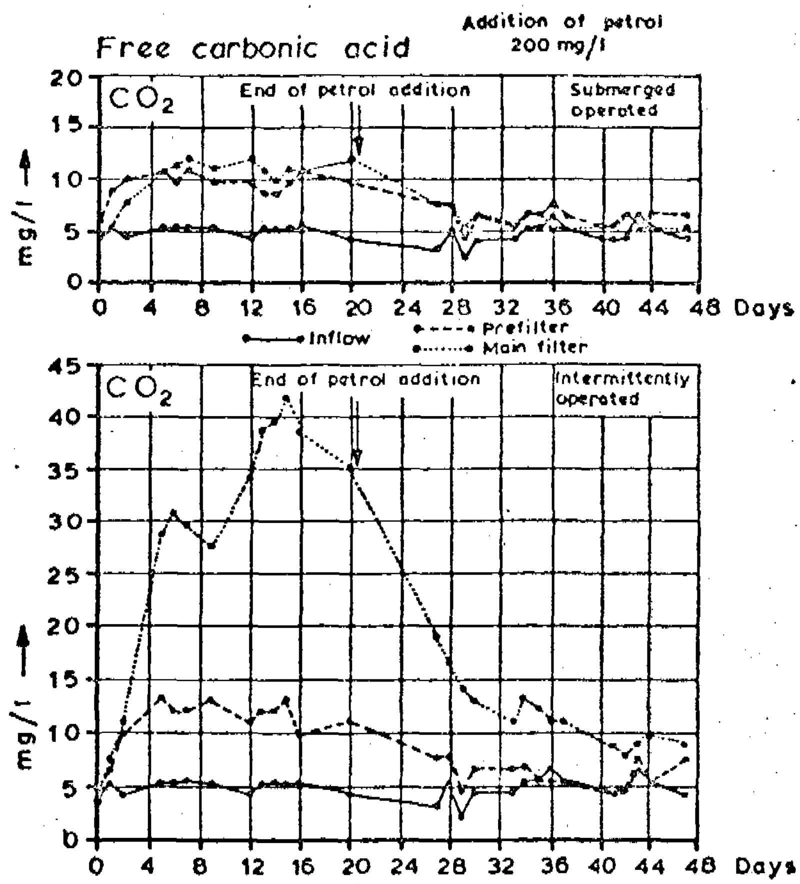

Fig.15 ADDITION OF PETROL TO SLOW SAND FILTERS

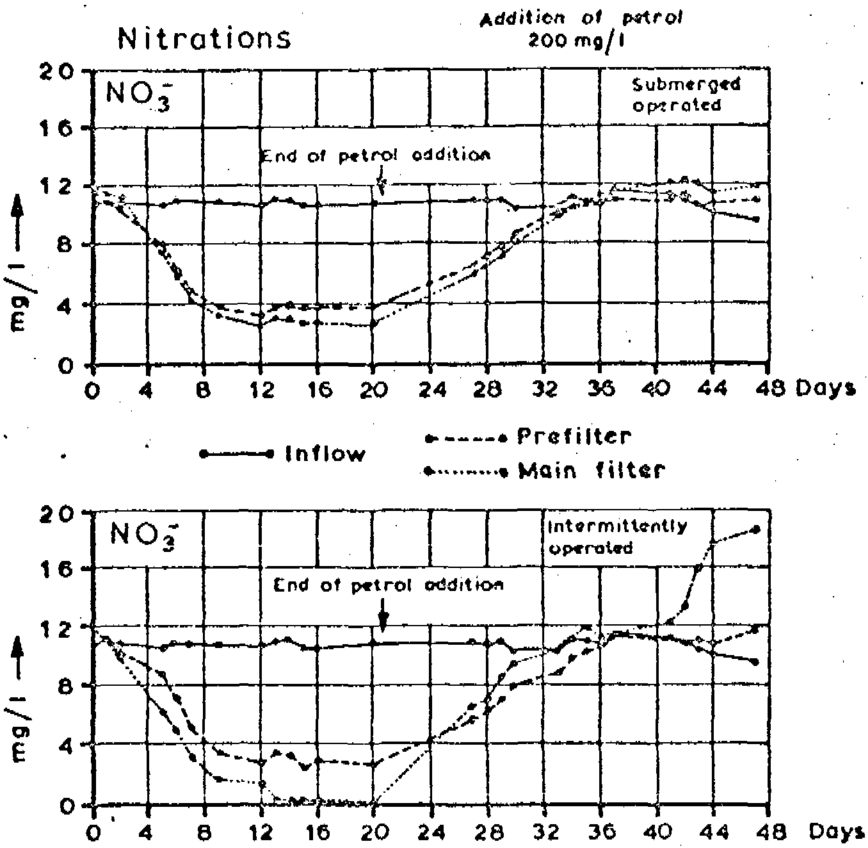

Fig.16 ADDITION OF PETROL TO SLOW SAND FILTERS

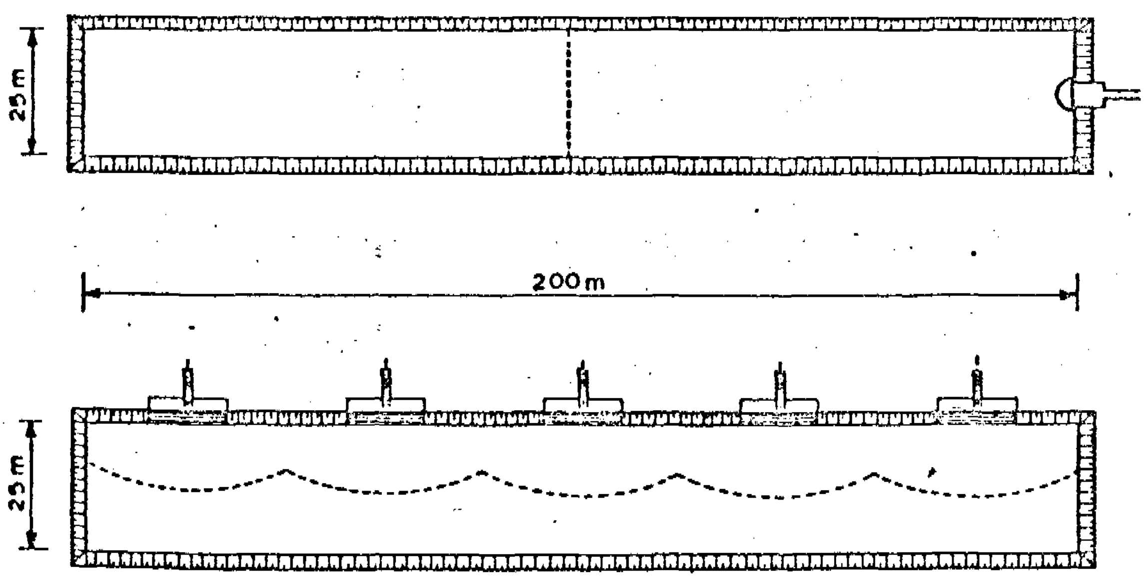

Fig. 18 OLD AND NEW DESIGN OF MAIN FILTRATION BASINS

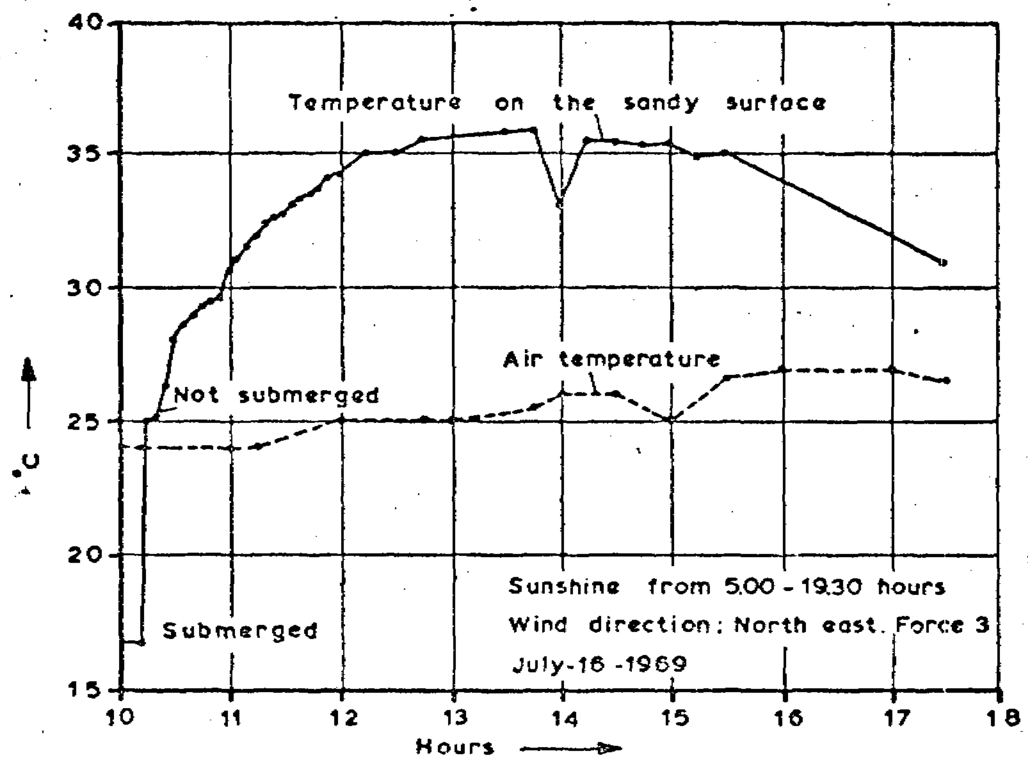

Fig. 19 TEMPERATURE ON THE SURFACE OF A DRY SAND FILTER

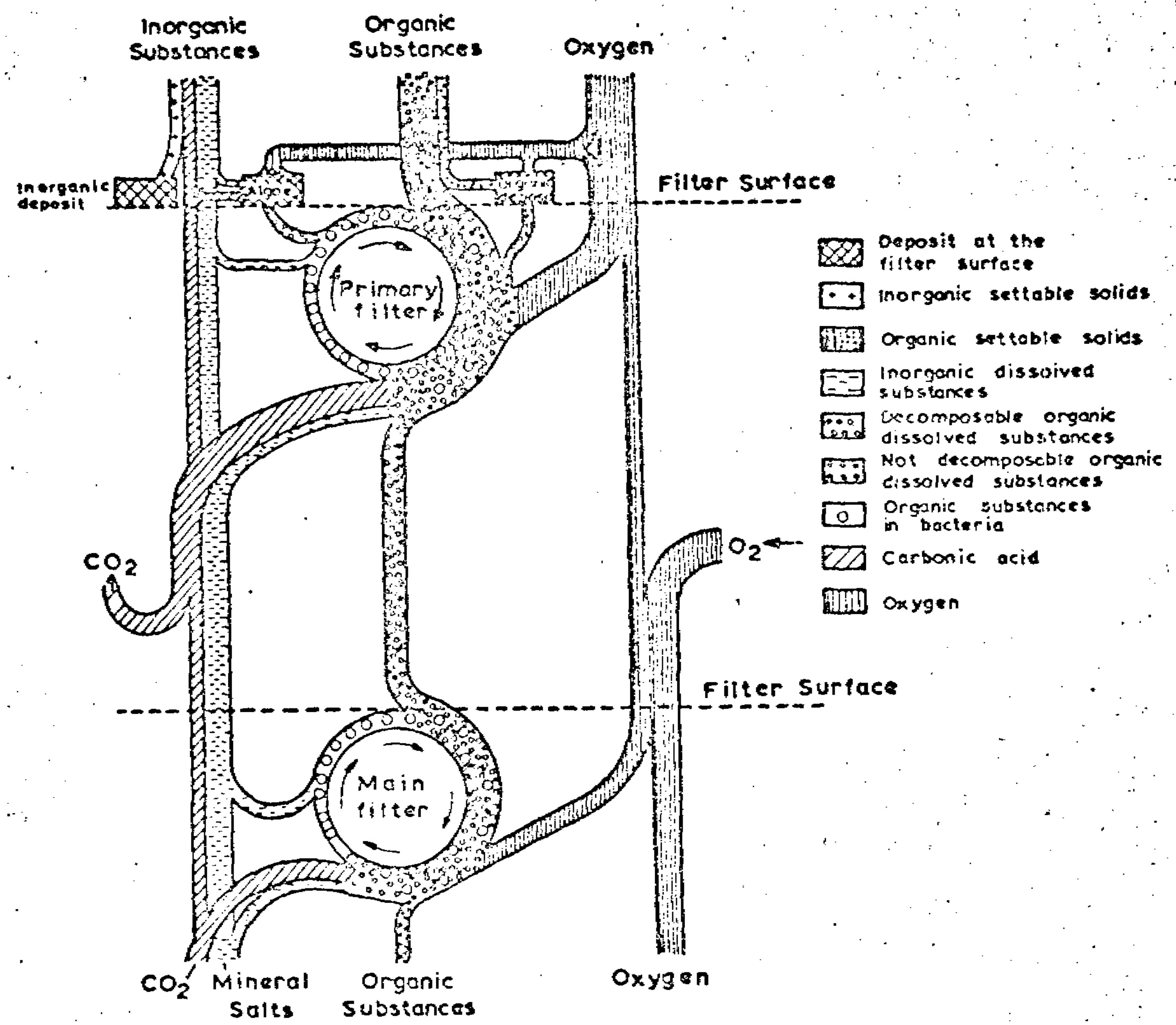

Fig. 20 SCHEME OF THE PURIFICATION EFFECT OF A TWO-STAGE SLOW SAND FILTER SYSTEM

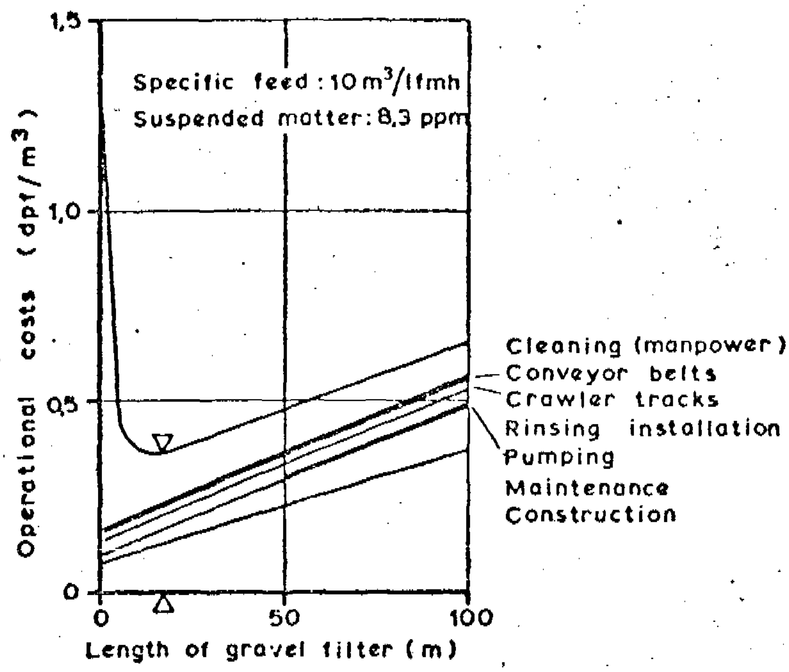

Fig. 21 OPERATIONAL COSTS FOR GRAVEL FILTERS

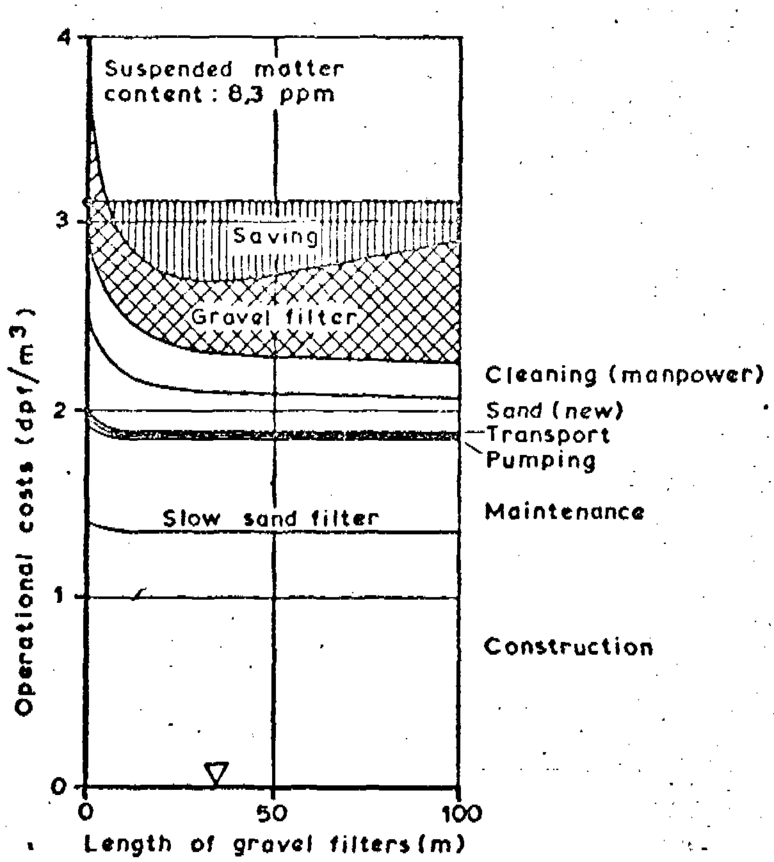

Fig.22 OPERATIONAL COSTS OF SLOW SAND FILTRATION WITH GRAVEL PREFILTERS

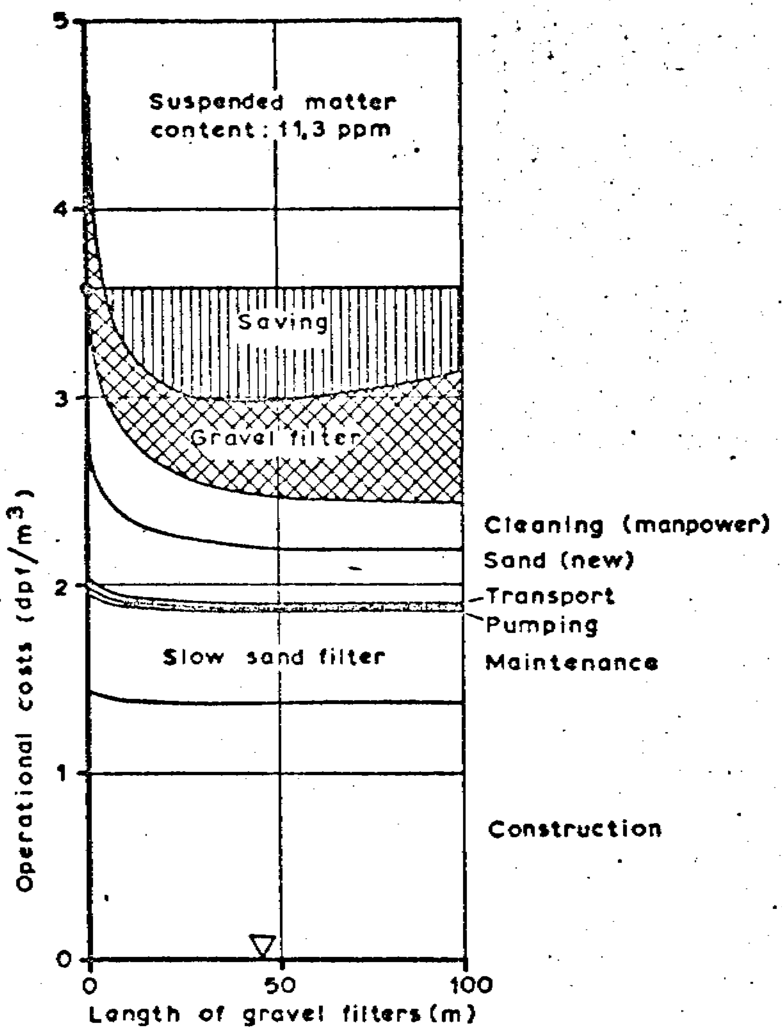

Fig 23 OPERATIONAL COSTS OF SLOW SAND FILTRATION WITH GRAVEL PREFILTERS