# Studies on the Fluidised Bed Reactor for Wastewater Treatment

**N. H. BAEK M. Sc.**

*Environmental Research Lab.,*
*Korea Atomic Energy Research Institute*

**I. Walker D. Phil.**

*Simon-Hartley Ltd.*
*Stoke-on-Trent, England*

## 요 약

이 유동층 폐수처리 방법은 처리능력이 한계점에 이른 기존시설의 확충, 탈질화반응(Denitrification), 산업폐수 처리 등에 응용될 수 있는 공정이다. 주된 특징으로는 박테리아나 원생동물의 성장을 돕고 처리 유용면적을 증대시키기 위해 망상형(reticulated) 유동입자를 사용하고, 그 안에서 호기성 소화(Aerobic Digestion)와 혐기성 소화(Anaerobic Digestion)를 시킬 수 있으며 직접 매립할 수 있는 고밀도의 sludge(5-7%)를 얻을 수 있다. 초기 시험단계인 만큼 값싸고 적절한 유동입자의 확보, 폐수의 시간적·계절적 변화에 따른 영향 규명, 수학적 모델 개발 등 많은 연구가 계속되어야 하지만 기존 공정에 비해 경제성이 높을 것으로, 본 실험연구를 통해 사료된다.

## ABSTRACT

This fluidised process seems very promising additions to the range of systems which can be used to up-rate existing sewage treatment plants, for denitrification, and to deal with industrial wastes. Because it retains such an active biomass within supporting particles, it will offer both aerobic digestion and anaerobic one. Concentrated sludges (5-7 % dry solids) may be produced for direct land disposal. The ability of this system is still to be tested in such aspects as cheaper and suitable particles and capapility of handling both diurnal and storm flow. However it will show savings in total cost when compared with conventional system.

## 1. Introduction

The nonsettleable organic content in sewage is usually being removed by either the suspended growth activated sludge process or the attached growth activated sludge process. Both of them require large areas of land enough to achieve a given degree of treatment. Recently there has been a general move towards a higher standard of effluent discharge in terms of nitrogen content.

This process, which has developed from work on denitrification of sewage effluents,[1,2] employs expanded or fluidised beds of sand or other small media which have a very large surface area (per unit volume) upon which the biomass grows as thin films. It is possible in fluidised bed reactors to achieve biomass concentration BTS of the order of 15-40 g/$l$[3], compared with 3-5 g MLSS/$l$ that is usually the upper limit in conventional activated sludge systems because of the difficulty in settling higher concentrations of mixed liquor. Downflow biological filters suffer from blockages if a medium of very small size is used in order to develop a high biomass concentration such blockages do not occur in fluidised beds because the particles are kept in suspension.

The treatment of sewage which retains low organic carbon content requires two reactors, anaerobic and aerobic, and also needs such a suitable carbon source for anaerobic digestion as methanol,[4] molasses,[5] and petrochemical waste.[6] But in this process which consists of passing wastewater up through a bed of plastic mesh particles under conditions that impart a motion to fluidise the particles, both of reactions occur in one column and do not need to feed any substantial carbon source. This can lead to a 8-10 folds reduction in reactor-size, resulting in a significant reduction in capital cost of the plant needed to achieve a given degree of treatment.

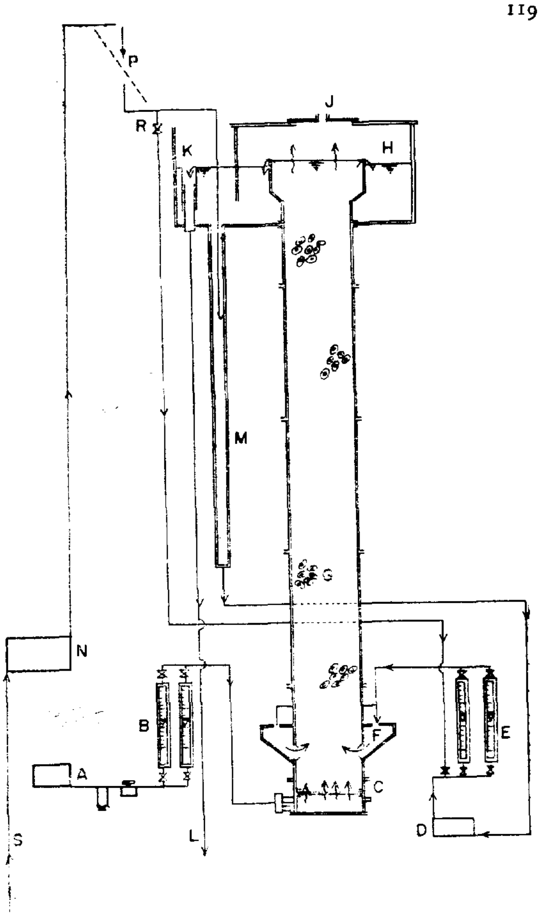
This report discusses the basic observation of this process, named Captor Process, regarding the basic principle of fluidisation and the biological properties of the bed.

## 2. Review

Jeris, Beer, and Mueller[2] proceeded to the concept of using fluidised media for growing high concentrations of biomass for denitrification in the same way that Bailey and Thomas[1] had proceeded independently to the expanded. Beer[7] suggested the use of fluidised granular media such as activated carbon, sand, or glass beads. Francis and co-workers[8,9] at Oak Ridge National Laboratory, Tennessee, extended the use of anoxic flusdised beds for denitrification from the relatively low concentration of nitrate (20-40mg N/$l$) present in sewage effluents to the much more concentrated wastes (226-2260mg $No_3$-N/$l$) of the nuclear fuel reprocessing field. A novel feature of the system Francis used was the concept of a pyramidal or conical fluidised bed to reduce the velocity as the liquid passed up through the bed and prevent coated media being displaced from the reactor by the co-current flow of liquid and the large quantity of nitrogen gas bubbles produced. Bosman[5] applied the technique to treating the concentrated nitrate waste from a chemical complex producing fertilizers and explosives. An interesting feature of her work was the use of a low cost by-product, molasses, as the carbon source, Klapwijk[10,11] also used in anoxic fluidised bed of activated sludge particles to achieve denitrification of a sewage effluent. He used both exogenous and endogenous respiration and consequently needed a retention period of 1.2 hr in the anoxic reactor. After summarizing all the work that has been reported on anoxic denitrifying fluidised bed systems, it is very attractive using activated sludge particles in fluidised beds because of no need for sand/biomass separation.

Jeris and co-workers[12] Progressed from their anoxic denitrification work in fluidised bed reactors to using a single 0.6m dia. x 4.6m high biological fluidised bed for both carbonaceous and nitrogenous oxidation. They used commercial oxygen and a downflow bubble contactor[13] to achieve dissolution of the very high concentration of oxygen needed externally to the reactor. Sehic[14] also examined the use of a biological fluidised bed to oxidise the organics and ammonia present in a settled sewage, but he used air rather than the commercial oxygen used by previous workers. Using a separate aeration tower and a very large (up to 13:1) recycle around the system he achieved greater than 90 percent removal of BOD from a settled domestic sewage (BOD 220mg/$l$) at retention periods in the range 43-57 min., BVS concentrations of 5.2-13.0g/$l$, and sludge ages of 1.3-3.2 days. Short[15,16] used a fluidised bed of river silt solids and fine sand (50-150$\mu$m) to oxidise the ammonia present in river wather (<5mg $NH_3$-N/$l$). In most of the work reported, oxygen was not added since there was sufficiently present in the river water. No quantitative measurement was made of the biomass concentration, but it was noted that "rate of nitrification was found to be a function of the ammonia, oxygen, and active solids concentrations".

Recent work at the Wastewater Technology Centre in Canada[17] has been aimed at establishing the process response of an oxygenic fluidised bed system to change in temperature, hydraulic retention period, recycle ratio, effluent dissolved oxygen concentration, and influent organic concentration.




*A* Air Compressor: delivery of upto 5.7 l/sec
*B* Rotameters: one at 80 l/min, one at 200 l/min
*C* Air Distributor: sintered plastic plate
*D* Recycle Pump: delivery of upto 8m$^3$/hr
*E* Rotameters: one standby
*F* Feed/Recycle Distributor
*G* Column
*H* Degassor Box
*J* Removable Vent
*K* Variable Height Overflow
*L* Effluent Drain
*M* Recycle Tube
*N* Feed Pump: variable speed, delivery upto 2.5 m$^3$/hr
*P* Screening Box
*R* Feed Line
*S* Primary Settlement Tank

PilotPlant Specifications:
Overall height 4.57m
Column diameter 45cm
Column volume 0.6m$^3$
Construction: 3 identical sections with four glands to take D.O./pH probes
1 air distributor
1 feed distributor
All sections are flanged and interchangeable

**Fig. 1.** Schematic Diagram of the Pilot Plant

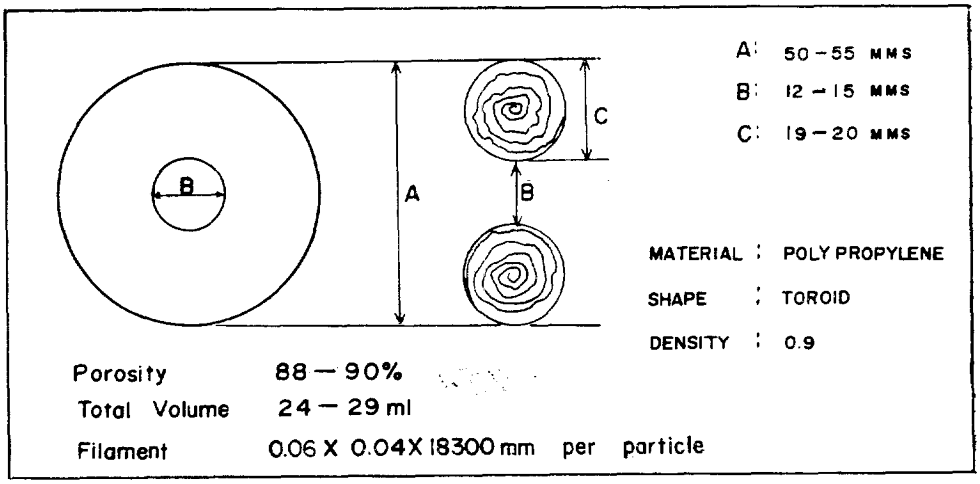



**Fig. 2.** The Particle used

## 3. Experiment

This apparatus has been designed to cover virtually two aspects of fluidised bed treatment methods which has already been mentioned. It is shown schematically in *Fig. 1*, and the particle in *Fig. 2* Essentially it consists of a column with an air diffuser and a feed distributor at its base and an overflow system at its top. The column is constructed in sections so that its height can be varied from 2m total to 5m total. There is provision for continuous monitoring and recording of dissolved oxygen levels at four of ten points and pH and temperature at one of ten points. The flow rate is also monitored constantly. The centre column is supported by an access gantry and it is intended to enclose the structure with corrugated plastic sheeting.

Settled sewage will be subjected to fine screening and then fed to either the base of the column or the recycle tube. It will be possible to work with sewage retention times down to around 10 minutes. Effluent will be discharged to a weir tank without clarification but it will be possible to bypass a part of the flow to a small tank to collect solids. The recycle flow can be driven by the air lift and can be controlled by the effluent over flow weir or supplemented by the recycle pump. When using heavy particles,

**Table 1.** Performance Data for Experiment

| | | Mean | Maximum | Minimum |
|---|---|---|---|---|
| **FEED** | | | | |
| $BOD_5$ | mg/l | 76.7 | 103 | 60 |
| S.S. | 〃 | 92.0 | 118 | 27 |
| $NO_3$-N | 〃 | 31.4 | 41.7 | 26.0 |
| $NH_3$-N | 〃 | 20.8 | 24.0 | 18.0 |
| Temperature* | °C | 16.4 | 17.6 | 14.7 |
| pH* | | 7.80 | 7.95 | 7.62 |
| **EFFLUENT** | | | | |
| $BOD_5$ | mg/l | 18.6 | 26.6 | 4.2 |
| S.S.** | 〃 | 34.6 | 51 | 8 |
| $NO_3$-N | 〃 | 15.4 | 21.1 | 13.0 |
| $NH_3$-N | 〃 | 19.6 | 23.4 | 17.3 |

*Measured at the centre of the bed.
**Taken into account till 50th day.

the recycle pump. will be used to fluidise the bed. Initial trials will be undertaken with a supply of domestic sewage specified in Table 1 at Audley local sewage works in Britain.

It has a total full volume of $0.6m^3$ which contains three backetful of particles dropped in at random. The air flow can be controlled upto 200$l$/min. According to the standard methods[18] all samples are analysed on BOD, suspended solid, Ammonia-N and Nitrate-N. From these data given in Table 1, two observations have primarily been made.

## 4. Result and Discussion

The function of the particles is to provide a large surface area for microbial attachment and also an environment of low shear so that thick films can develop. There are two possible constructions, cellular (such as a sponge) and reticular (such as a mesh), but, due to the probable limitations on diffusion within a cellular particle, the reticular construction is preferred. The successful particles are made from doughnut shape of polypropylene toroid manufactured as *Fig. 2*. The key to the whole process is that each particle has an aerobic outer zone and an anaerobic inner zone. The size of the anaerobic zone is governed by a few main factors such as the size of the particle, the strength of the waste being treated and the amount of air supplied to the system. The outer aerobic zone is responsible for most of the removal of the carbonaceous BOD and for the conversion of ammonia to nitrate through nitrification.

The inner anaerobic zone is responsible for the conversion of nitrate to nitrogen through denitrification and also the digestion of the sludge that has been built up during aerobic growth.

The biomass found within the particles is very similar to that found in activated sludge systems but there is a continuous gradation from a light zoological sludge with many protozoans (*Fig. 3*) on the outside of the particles to a black dense granular sludge devoid of visible signs of activity at the centre.

*Fig. 4* is a representation of a section across one particle and gives an indication of the expected locations of the various biological reactions[19] that have been found to occur within the systems looked at,

Apart from this, the degree of fluidisation which is found to depend primarily on the air

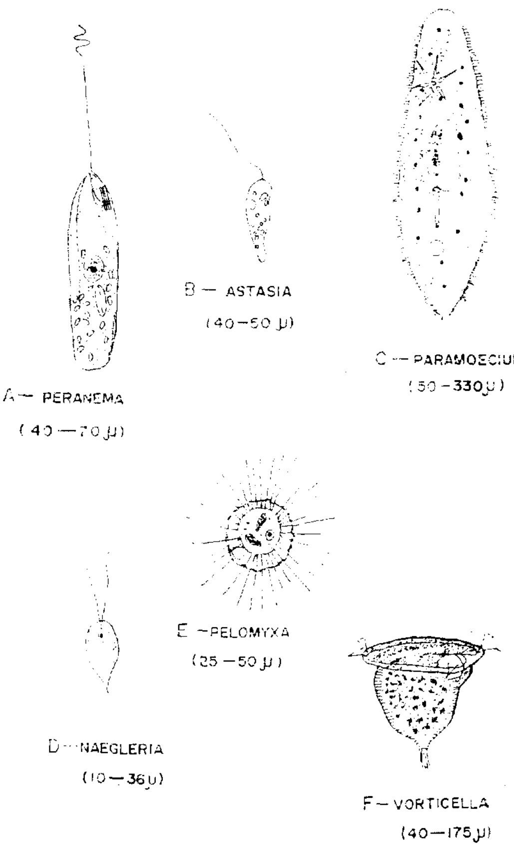



**Fig. 3.** Protozoa found Within Active Biomass in Fluidised Bed Reactor

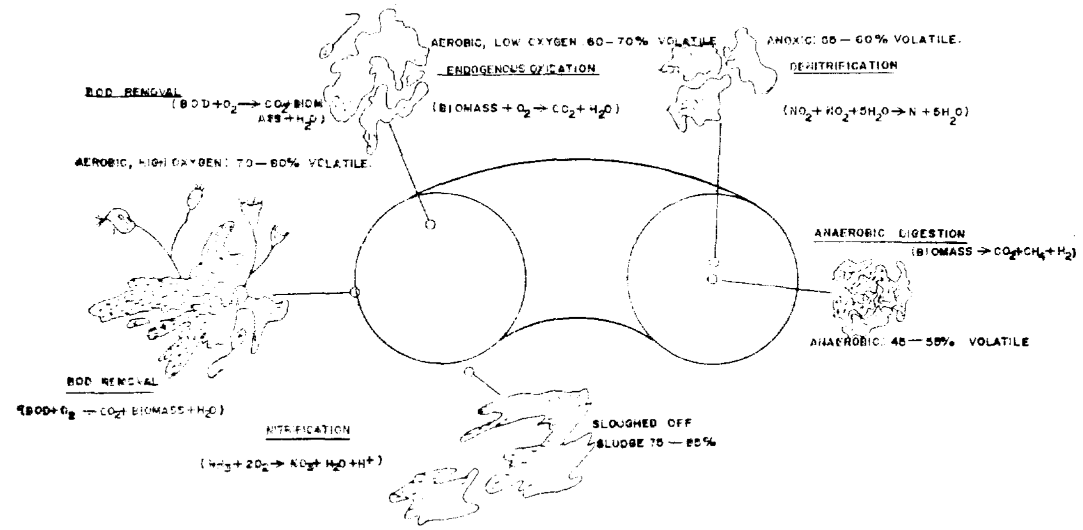



**Fig. 4.** Cross Section of a Toroid Showing the Different Populations and Reactions

which flow is too low then the particles remain floating at the top till the density of the fluidised bed reaches the same as one of

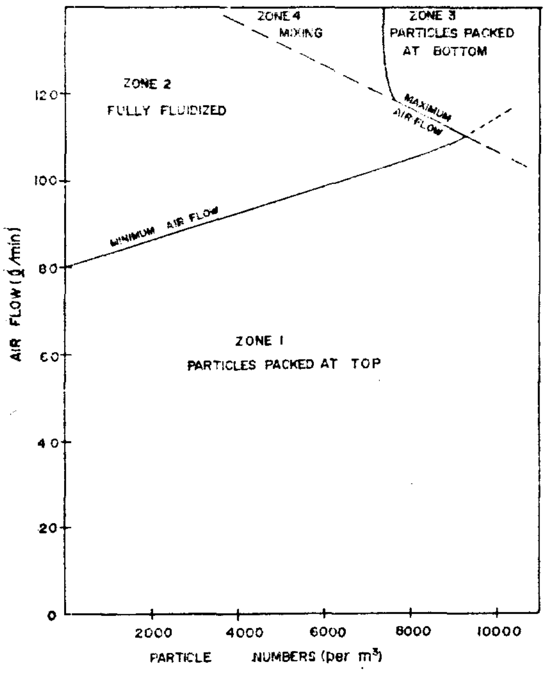



**Fig. 5.** Fluidisation Diagram for Toroids, Each Contains 0.8g (d/w) Biomass

particles, On the other hand if the flow is too high, there is a tendency for the particles to pack at the bottom. The actual flow of air at which complete fluidity can be achieved is, however, dependent on two factors as follows:

### 4-1. Particle Numbers

The effect of particle numbers on fluidisation can be seen in *Fig,5*. This shows the limits of true fluidisation with different numbers of particles per $m^3$; each particle contains on average 0.8g of biomass (dry weight). The critical number is found to be 9200 per $m^3$; if more than these are present, it proves to be impossible to keep the whole bed fluidisation, due to particles packing at the bottom before the top part of the bed is moving. The theoretical maximum number of particles with a diameter of 52mm that can be contained in one $m^3$ is 9132[20]. This figure is, to all purposes, identical with the maximum number of particles that can be kept fluidised. when there are 9132 present, each particle has enough room for unrestrictive movement.

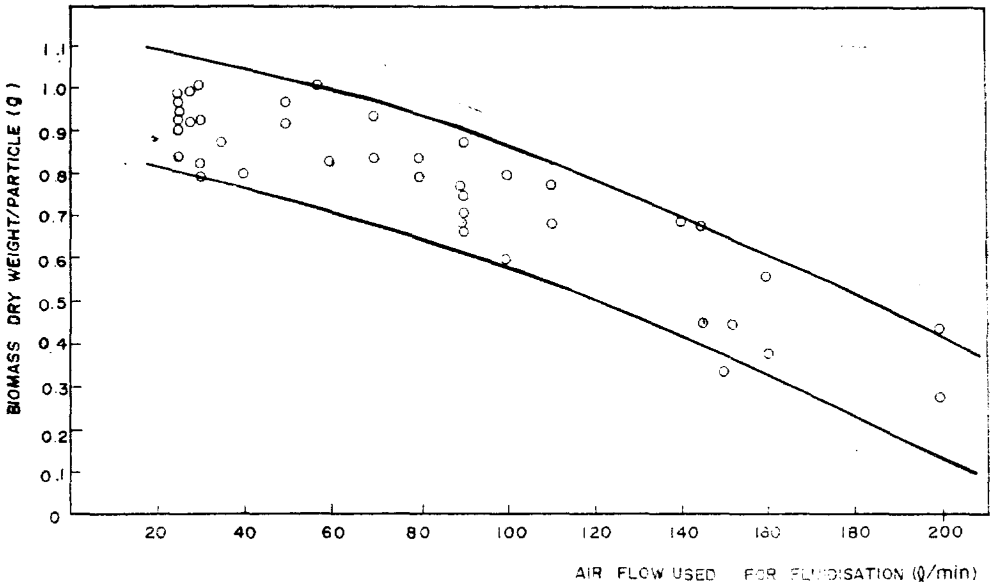



**Fig. 6.** Effect of Biomass Hold up on Air Flows Required for Fluidisation

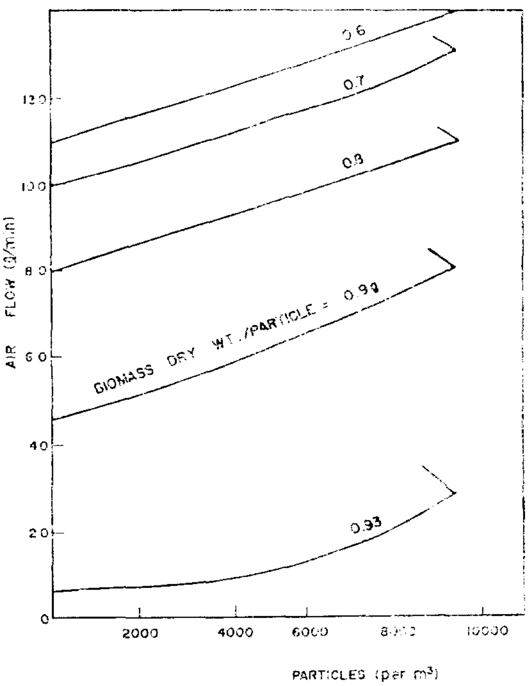



**Fig. 7.** Minimum Air Flows Required for Fluidisation at Different Biomass Hold ups (these lines are estimated)

It is possible to induce bottom packing of the particles by havng excessive air flows only when there are more than about 7500 particles per m$^3$. when there are less than these, it is possible to have a pseudo fluid state wherein the particles are mixed by the turbulence associated with high air flows. It is considered that there is a damping effect, due to the closeness of the particles, when there are more than 7500 per m$^3$ which prevents the mixing effect occuring. The location of the different zones in *Fig. 5* can be dramatically modified by the second factor that has an important influence on fluidisation, the concentration of biomass within the particle.

### 4-2. Biomass Concentration

It is found that the air flow required to give complete fluidity decreases as the dry weight of sludge holds within each particle increased; the relationship is shown in *Fig. 6*. The degree of scatter is high because the

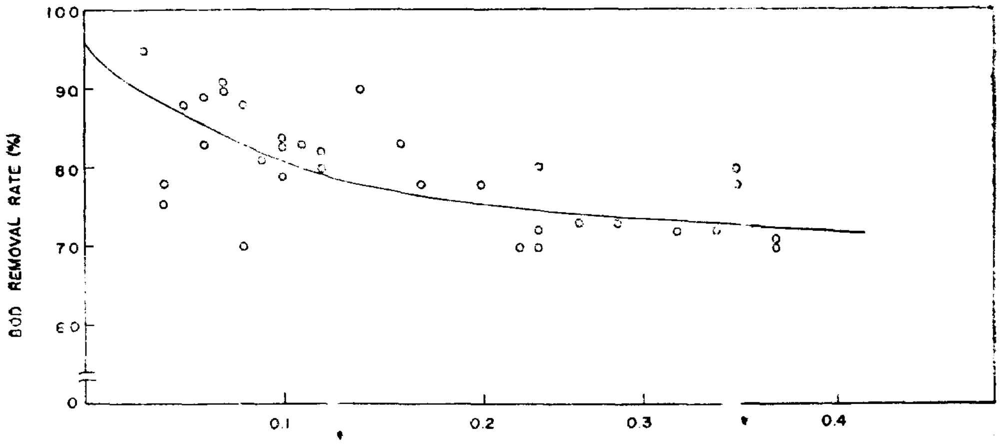


**Fig. 8.** BOD Removal Rate

figures used for the air flows are not necessarily the minimum air flows as defined in *Fig. 5*, the points are therefore enclosed by two lines rather than having a line drawn through them. This effect can be readily explained in terms of increased net densities of the particles with increased biomass hold-up. And *Fig. 7* shows the minimum air flows estimated for a range of biomass hold-ups and different numbers of particles. The fluidisation zone is much more restricted at the higher biomass hold-ups.

From this figures presented, it would appear that the maximum biomass hold-up obtainable with the toroidal particles is around 10000 mgs per litre, assuming 9200 particles per $m^3$ and 1.05g per particle. Attempts to increase this value by adding more particles would result in overgrowth of these particles that would be packed at the bottom, even at a high removal rate of particles for washing. Increasing air flow would also create sloughing off by turbulence if it were tried in order to keep the bed fluidising.

On the other hand it is found that BOD (ref.: *Fig*: *8*) and Suspended Solid (ref.: *Fig. 9*) removal are acceptable with only the odd exception. (ref.: British Royal Commission Standard BOD$<$20mg/$l$S.S. $<$30mg/$l$). A well nitrified effluent is found after 2 weeks while

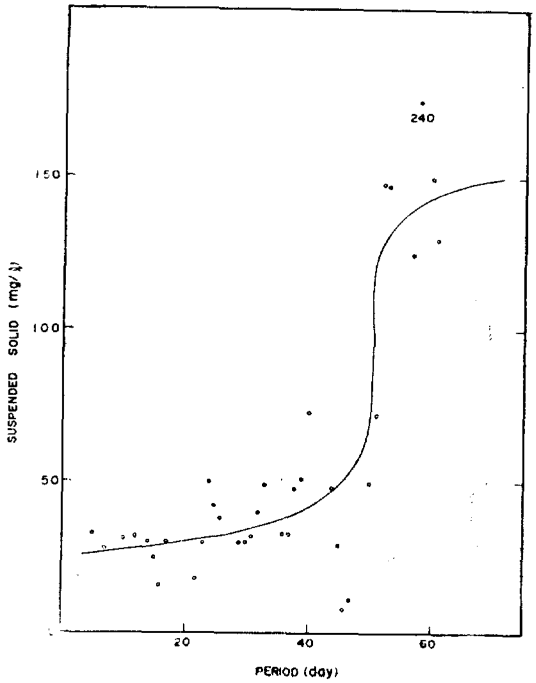


**Fig. 9.** Suspended Solid in Effluent

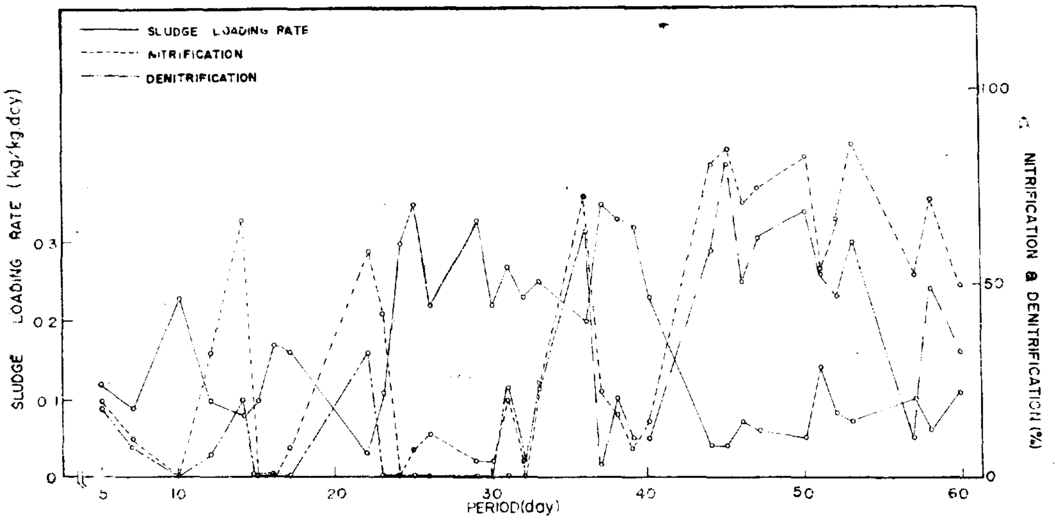



**Fig. 10.** Nitrification and Denitrification

the particles is becoming covered with an active biomass. As increasing the loading rate, nitrogen metabolism starts to be disappeared and sloughing off (ref.: *Fig. 10*). As the biomass ages. it is expected that it will become mineralised and reveal the following values;

Ash Content of Outer Layer: 29.3%

Ash Content of Inner Layer: 36.7%

Ash Content of Effluent: 24%

It is likely that the ash content increases almost linearly with the distance from the outside, and that the solids at the centre may well be around 50% or more ash. It is thought that, due to mineralisation, the net sludge age could be 20-25 days.

It can be seen in *Table 1* that, in general, it is possible to produce a reasonable efflunt, even with retention times as short as 12 minutes. However it is unlikely that the effluent quality could be improved without reducing the loading rates to unacceptably low levels because of the physical constraints imposed by the particle shape. The amount of biomass available for aerobic dissimilation of BOD and for conversion of $NH_3$ to $NO_2$ and $NO_3$ is too small; that is the ratio of surface area to total volume for a toroid is too small at 1.38$cm^{-1}$. Nitrification in this trial does not indicate to function as much as conventional system which would yield 100% nitrification at below 0.1kg/biomass kg/day[21], It is likely that nitrifiers can remain within the system at higher loadings because they are captive within the mesh and therefore not washed out so readily. It is also clear from *Fig. 10* that denitrification occurs with up to 80% removal of nitrogen having been effected. Although it is expected that only the outer layers of the particles will be available for aerobic treatment, it is not expected to be such a small proportion. The proportion can be increased by decreasing the tubular diameter (dimension C in *Fig. 2*) or by changing the shape of the particles completely. Despite this disabvantage the toroid proved to be extremely durable, showed no tendency to packing and in general operated on a stable basis.

## 5. Concluson

This trials show very clearly that the biomass is retained within the particles as an active biomass. Microscopic examination of the balls reveals a dark gritty sludge at the centre, devoid of any protozoan life and a light brown and diffuse sludge at the surface, with a complex protozoan population, There is a gradation between these two extremes across the ball. This will offer to achieve an acceptable level of wastewater treatment in such an aspect as BOD and S.S. removal, nitrification and denitrification.

Having filled an aeration vessel with support particles, it becomes important to keep the bed fluidising. In aerobic systems, the use of air induced fluidisation has a dual functions; The most satisfactory way to the inproved mixing regime for better oxygen transfer and consequently to control overgrowth which would result in the bed becoming blocked and prevent the easy passage of wastewater. The support particles are limited to having a density less than one (e.g. plastic material) so as to maintain the bed in a fluidised state.

As a result this system offers considerable reduction in both the volume of a reactor and the throughput of effluent to be treated. The principal advantage, however, appears to be the low sludge production, that is higher mineralisation, with the possibility of running a system without a final clarifier. This prospect is much more likely at the low loadings required for nitrogen removal. At higher loadings a small humus tank may be required. The sludge produced settles readily and should dewater easily. The sludge obtained would already be at 5% d/w and the activity of the particles would not be reduced too much; The particles could then be returned to the reactor after being squeezed to remove most of sludge.

## 6. Summary

with the onset of more rigid standards being imposed on effluent discharges, many industrial and municipal concerns will be installing new waste treatment facilities or upgrading existing ones. This process, one example of new technologies, has aerobic and anaerobic environments in one column by using biomass within supporting particles. In this first stages of the evaluation of this process, the valuable information has been provided regarding the basic principles of fluidising particles and shown that, from a biological viewpoint, the process is so viable that it should result in the reduction of waste water treatment facilities by a factor of 8-10 in size. It is stable, flexible in application and simple to operate.

However further development must be directed towards the use of other particles which are cheaper and have a greater ratio of aerobic to anaerobic zone and produce sludge at higher concentration. There must be also some other trials to find the effect of shock high and low loadings and the potential for treating single source industrial wastes e. g. food processing, brewery, etc.

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## Abbreviations

| | |
|---|---|
| *BOD* | Biological Oxygen Demand |
| *BTS* | Biomass Total Solid in the fluidised state |
| *BVS* | Biomass Volatile Solid in the fluidised state |
| *MLSS* | Mixed Lipuor Suspended Solid |
| *S.S.* | Suspended Solid |
| *d/w* | dry weight |