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# A study on biflow filtration

### Introduction

Ever since James Simpson in 1829 designed the first slow sand filter in England thus providing the first major break-through in the municipal's engineers quest for pure water to satisfy an increasingly health conscious domestic demand, as well as the needs of industry for bulk supplies of relatively pure water, it was but natural that researches in the field of public health engineering direct their endeavours towards achieving a greater efficiency in the process. Now efficiency of the process of mass clarification of water, can most logically be measured in terms of two factors — one, the quality of water produced and two the unit cost. The first presented no problem. The process of filtration through graded sand is by itself a most satisfactory one, as far as the quality of effluent is considered. Besides, large amount of research work on media characteristics, like size, grading and depth has established a wide know-how that together with allied processes of pretreatment enables the engineers to purify water to a degree that would satisfy the most rigorous standard.

Efforts towards achieving a lower unit cost would, for obvious reasons, be considered with increasing the rate of filtration per unit area of the filter surface and it did. The rapid sand filter designed at the turn of the century in America, utilised the boon of the age 'mechanisation' to startling advantage. The rate of filtration was accelerated sixty times and the resultant decrease in bacteriological quality was offset by the newly developed process of sterilisation with chlorine.

The rapid sand filtration technique became the basis of design for most water supply schemes all over the world. In India, also most municipalities and metropolitan councils based their water purification plants on this technique. But, however, with the increase in demand for water due to industrialisation and consequent spurt in business and trade activities and urbanisation, there began to exist a huge hiatus between demand and supply in many cities and industrial areas.

Research in India has, therefore, turned with in creasing interest towards the hitherto neglected technique of biflow filtration, which the Russians and the Dutch have utilised to amazing advantage, in the operation of their municipal water plants for some time. The Russians faced with a problem similar to India's have embarked since 1952 on converting their oneway filters to the present day „AKX" model, which operates on the biflow system.

Biflow filtration consists in using a filter bed of a virtually similar character as the one way rapid sand filter and allowing the unfiltered water to pass from both ends of the filter bed with a collection device, situated somewhere intermediate along the depth. Whereas the normal rate of filtration by the rapid sand filter process is 120 lit/min/$m^2$, biflow filtration doubles the filtration rate to a normal about 250 lit/min/$^2$. Whatever of very little Russian performance charts are available (as shown in table I and II), they indicate the operating characteristics, that are in no way inferior to those of the one way filter except for a shorter length of run, which is however more than offset by the much more considerable increase in the rate of filtration. It is also found that the overall efficiency of a plant operating on the biflow technique is 17 times, that of the same plant, operating on the conventional one way system.

Existing filters can with ease be converted to the biflow pattern and the construction cost would virtually be limited to the slight initial expenditure on a modification of the piping and valving system for the plant. It is also of interest to note that the cost of constructing a new plant on the biflow system is 15 % to 30 % less than the conventional filters in Russia.

TABLE I - *Average operating characteristics of normal rapid filters. AKX filters and contact clarifiers in USSR*

| operation | | rapid filter | AKX filter | contact clarifier |
|---|---|---|---|---|
| Design filtration rate | gall/sqft/hr | 125 | 250 | 100 |
| Maxm. filtration rate | gall/sqft/hr | 150 | 300 | 100 |
| Basic. wash water rate | in/min | 16 | 21 | 20 |
| Wash duration | min | 5 | 6 | 8 |
| Top layer wash rate | in/min | 0 | 8 | 0 |
| Top layer wash duration | min | 0 | 1 | 0 |
| Flush rate through | in/min | 0 | 13 | 0 |
| filtrate collector | min | 0 | 2 | 0 |
| Flush duration | min. | 0 | 2 | 0 |
| Initial filtrate to waste duration | min | 0 | 0 | 5 |
| Time out for cleaning | min | 20 | 24 | 28 |
| Filter run | hours | 12 | 12 | 20 |
| Operation cycle run + wash | hours | 12.33 | 12.4 | 20.47 |
| Filtrate output per filter run | gal/sqlft. | 1,500 | 3,000 | 2,000 |
| Coagulant dose (Anhydreous salt) | mg/lit | 25 | 25 | 20 |
| Lime dose | mg/lit | 6.6 | 6.6 | 0 |
| Bacterial removal (colony plate count) | ./. | 74 | 71 | — |

*Note:* 1 gal (UK)/sq.ft./min = 2.924 $m^3/m^2$/hour
1 inch/min = 0.52 gal/sq.ft./min

TABLE II - *Comparison between conventional rapid filter and rapid filter reconstructed to AKX pattern in USSR*

| Operation | Units | Rapid Filter | AKX filter (reconstructed) |
|---|---|---|---|
| Rate of filtration | gal/sq.ft./hr | 125 | 250 |
| Filtered water output | million gal/month | 135 | 240 |
| Wash water used | million gal/month | 3.6 | 8.5 |
| Wash water used | ./. | 2.45 | 3.5 |
| Basic wash rate | in/min | 20.5 | 18 |
| Top layer wash rate | in/min | 0 | 16 |
| Basic wash duration | min | 4.5 | 7 |
| Top layer wash duration | min | 0 | 3 |
| Washes per month | no. | 29 | 34 |
| Average filter run | hours | 24-50 | 21 |
| Comparative efficiency | ./. | 100 | 177.2 |
| Initial head loss | ft. | 1.6 | 2.6 |
| Final head loss | ft. | 7.5 | 7.8 |
| Filtrate turbidity Silica scale | mg/lit. | not given | 2-3 |

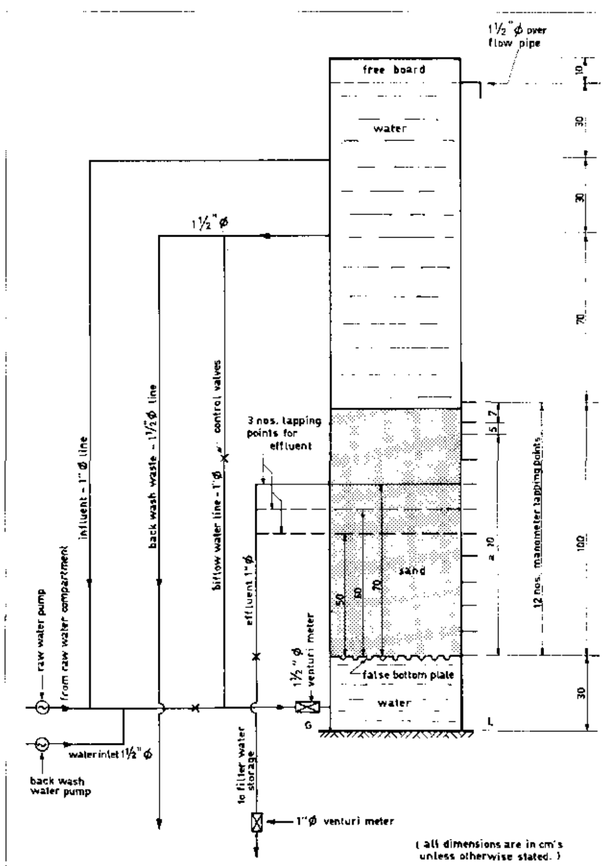



*Fig. 1 - Schematic diagram of the experimental set-up biflow filter unit.*

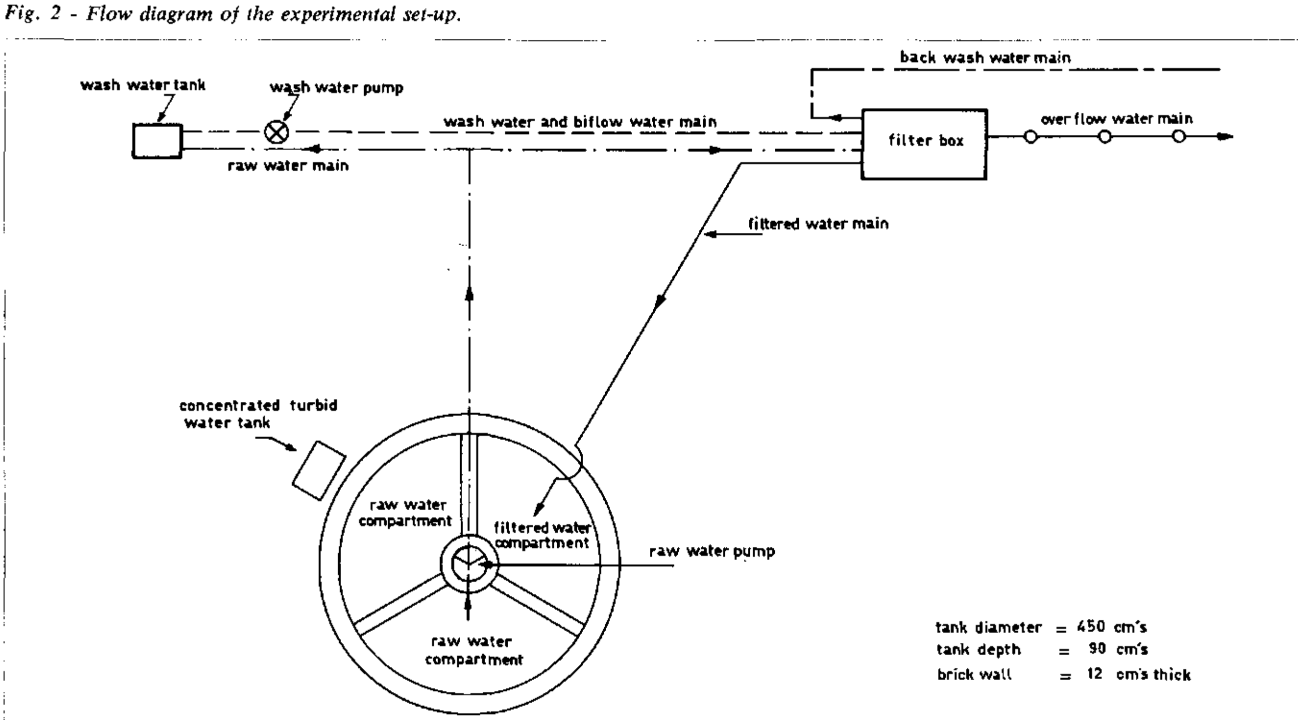
**Short history of biflow filter and review of literature**

The concept of filtration from coarse through successively finer grains was first referred to by Baker [1] in his book on „The quest for pure water". However, the idea of filtering in both directions was not new, and was patented by the „Candy Filter Company" of London back in 1918 [2]. Although such a filter was proposed over 40 years ago, it has only recently been rediscovered and applied on a large scale in Russia as „AKX Filter" and in the Netherlands as „Dutch Immedium Filter" [3], the principle of both being the same, differing in name only.

The „AKX Filter" was developed in 1955 [2] at the Pamfilova academy of municipal economy in Russia. For such a filter the filtrate pipe is generally installed at the upper layer of a graded sand bed [4]. As the unfiltered water is supplied from the same external source, the same hydraulic head loss is experienced across the upper and lower sections of the filter. Consequently differing flow rate is kept constant from the filtrate pipe. As the pores become clogged, equal head losses are maintained across the two sections by natural self-adjustment of flow rate between the two sections, and more water will pass through the bottom with the gradual clogging of the top layer. The maintenance of hydraulic gradients to the buried filtrate pipe prevents upflow fluidisation of the filter media, yet it permits the full depth of the filter to be used in the removal of suspended solids. Though full details are not available with regard to the performence of the Dutch Immedium filters, it has nevertheless been indicated that more water can be treated to the limiting head loss than with a conventional filter containing the same grades of sands. Similarly the Russians have reported greater filtration rates for their „AKX Filters" and have also operated successfully at 250 lit/min/m$^2$, while still maintaining a filtrate quality, which conforms to their normal standard. The principle of biflow filtration, as discussed by Ives [5], shows the curve for head loss pattern of such a filter.

Dave [6] describes that flow through the biflow filters is of different nature from that in the regular gravity filters. Porosity and frictional resistance will act differently in the upper and lower parts as the first one is under compression and the second is in expansion. The

*Fig. 2 - Flow diagram of the experimental set-up.*



mechanism of filtration in the upper layer will mostly be straining and in the lower part it will be a combined action of straining and adsorption. The upper part will have two components of the curve, one due to the surface film, an abrupt drop, and the other of the slowly clogging pores due to suspended matter, which may be exponential. The lower part will consist entirely of the exponential nature, as full bed penetration can be expected.

Mintz [7, 8] reported in 1962 that about 1 million cubic meters (264 MGD) of water a day are purified for municipal use in Russia by this method. The Russian biflow filter uses sand as the filtering medium at depths of 145-165 cm. The filtrate collection system is usually located about 50-60 cms below the top layer of the sand.

The downward filtration rate is from 100-125 lit/min/m$^2$ and the upward rate for the bottom layer is 150-175 lit/min/m$^2$. Thus the total filtration rate is 250-300 lit/min/m$^2$. Backwashing is by upward flow at a rate of 13-15 lit/m$^2$/sec for 5-6 minutes. Initial costs for such filters are estimated to be 15 to 30 % less than for conventional filters in Russia.

In AKX filters it is very important that air does not get entrance into the pores of sand to fill it up. Experience in Russia shows that if feeding to the settling tanks is by means of weirs and when the settled water to the filters is fed through open channels, it absorbs a large amount of air. It is reported that this air saturation of clear water going to the filter can be prevented by delivering it to the settling tank through the submerged holes of channels of pipes with a fixed level of water in it.

**Experimental set-up and operation of the unit**

The unit was fabricated out of M.S plates on three sides and the perspex sheet on the fourth's to facilitate visual examination at all times. The dimension of the filter box was 29.5 x 29.5 x 270 cms. The total depth of 270 cms was arrived at by providing an expansion of 70 % for sand and biflow of water with a free board of 10 cms to the outlet. The filter sand was supported over a slotted plate covered with fine wire mesh so as to prevent leaking of sand. Gravel layers where not provided to support the sand. The effluent from the filter was collected by placing a 2.5 cms diameter G.I. pipe having slots of 3 mm diameter at 1 cm c/c. The pipe was wrapped with fine wire mesh to prevent coming out of sand. The experimental setup and other details are as shown in the diagram (1 and 2).

**Preparation of raw water to the filter**

A closed cycle of operation was followed i.e. effluent from the filter was used as influent again. A circular tank was divided into three compartments; one compartment was used for storage of filtered water for backwash and the other two for preparation of turbid water in succession for feeding into the filter. Make-up water was also used when needed.

The desired turbidity of 30 unit on average was made by the use of finely divided black cotton soil. A second rectangular tank was used to prepare concentrated turbid solution. This concentrated turbid solution was mixed with the water in the compartments of the second circular tank to give the required amount of turbidity.

The coagulant used was filter alum. The method of application was concentrated dosage method. The required amount of coagulant needed for water stored in each compartment was added at a time in agreement with turbidity and volume of water in the compartment which was subsequently been agitated for proper mixing. The required dose was kept between 14-16 mg/lit.

**Details of media**

For the experiment it was decided to use sand as uniform as possible. The sand passing through ASTM-40 (0.5) and retained on ASTM-35 (0.422 mm) was used as filter media. Taking uniform distribution of sand, the properties of the filter media so used are as follows

(1) effective size ($P_{10}$) = 0.43 mm

(2) uniformity coefficient $\left(\frac{P_{60}}{P_{10}}\right) = 1.09$

(3) sp. gravity 2.67

(4) porosity % 48

The sand constituted the filter media to a depth of 100 cms.

**Observation facilities**

To study head loss characteristics of the unit, 12 water manometers were provided at different levels along the depth as shown in the sketch. Manometer no. 1 was used only to measure static head. The manometers so provided helped direct measurement of head loss through the sand bed at different levels.

Raw water was at first admitted into the filter box with the help of a raw water pump. The water was then allowed to rise up to overflow level and the biflow water valve was then opened fully and kept completely open during the complete period of run. The effluent wheel valve was then slowly opened and adjusted to give the required filtration rate as noted by the difference of water column in a previously calibrated differential manometer, attached to the effluent venturimeter. The zero hour head loss is correspondingly noted. Head loss observations were subsequently recorded each after one hour interval. Samples of raw water from the overflow pipe and filtered water from the effluent pipe were also collected after one hour interval and analysed for turbidity alkalinity and pH. The upward flow rate was also measured by the help of a calibrated venturimeter installed in the back-wash line each after one hour. It was found to increase with the time as the downward flow decreases. But the total flow is kept constant. The effluent wheel valve is adjusted time to time to give the desired filtration rate.

**Restrictions for filter run and washing**

The head loss in the biflow filter as was reported by J. T. Ling [2] from Krugbos result on AKX Filter is 224 cms; where the sand depth used was 145-165 cms at the Pamfilova Academy of Municipal Economy.

For the present set-up it was not possible to run the filter to a head loss of 224 cms, as the maximum heads available across the effluent pipe for the three tapping points were 160 cms, 170 cms, and 180 cms. So the filter run for the present set-up was restricted to a terminal head loss of 160 cms, in most of the runs. For the sand used in this particular case and for the raw water turbidity of about

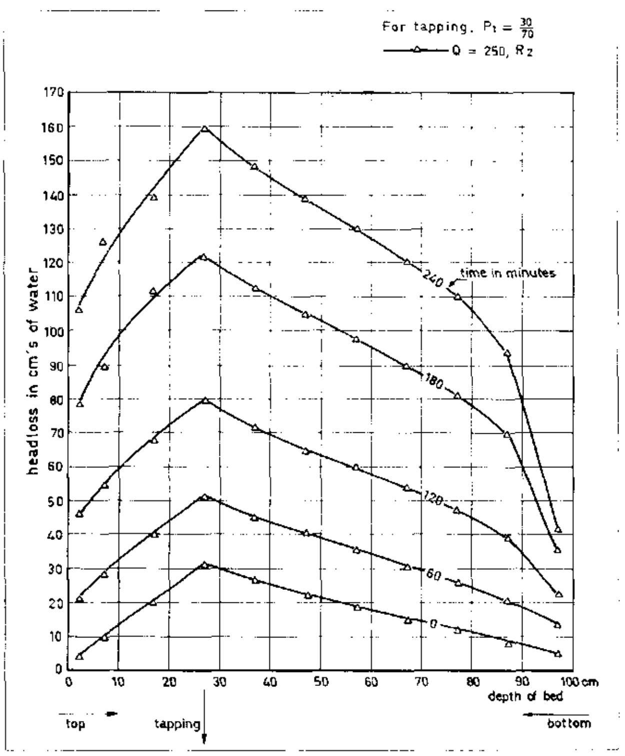



*Fig. 3 - Head loss VS depth of bed.*

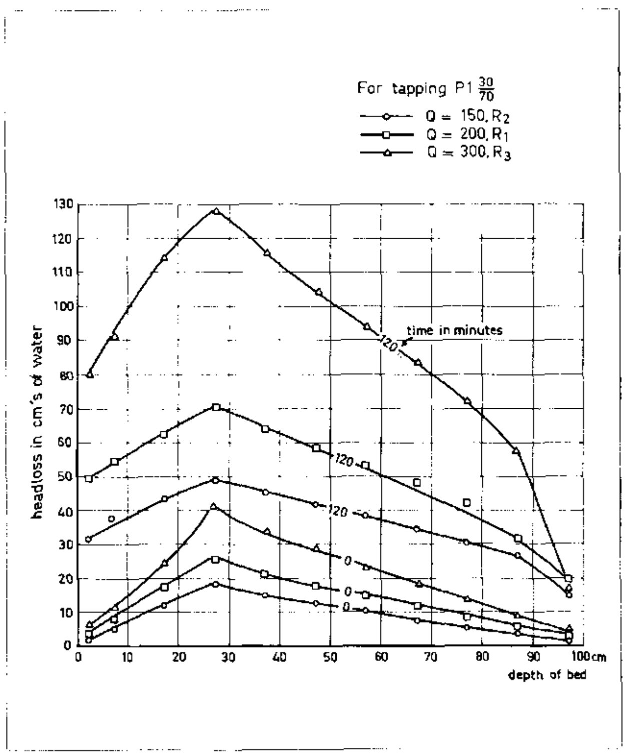



*Fig. 4 - Head loss VS depth of bed.*

30 units, it was found that this ceiling limit was reached at the end of

8 hours for the flow rate of 150 lit/min/m$^2$
6 hours for the flow rate of 200 lit/min/m$^2$
4 hours for the flow rate of 250 lit/min/m$^2$
2½ hours for the flow rate of 300 lit/min/m$^2$

Back-washing of the biflow filter is generally done at a higher flow rate. Mintz recommends [7] a flow rate of 13-15 lits/sec/m$^2$ for a period of 5-6 minutes whereas Ives [5] recommends a flow rate of 9 lit/sec/m$^2$ for a period of 6 minutes. It was considered to provide 70 % expansion of sand during washing. But due to set-up trouble a flow rate of 12 lits/sec/m$^2$ was adopted which gave an expansion of 40 % of sand for a period of 6 min.

## Observations

The pilot plant was operated for a period of 1.5 month with the following flow rates at three tapping points of the filtrate as shown in the set-up drawing.

Turbidity measurement was carried out by a „Universal photo-electric colorimeter" after being standardised with Hellige turbid solution. On an average the influent turbidity never exceeded 41 units and on average, 30 units for most of the runs. The effluent turbidity in most of the cases was nearly 2 units.

The flow was measured with the help of two venturimeters of 2.5 cms and 3.75 cms diameter installed in the

*Observation data*

| time of operation minutes | influent temp. ° C | influent turbidity units | effluent turbidity units | upward flow lit/min/m$^2$ | downward flow lit/min/m$^2$ | remarks |
|---|---|---|---|---|---|---|
| 0 | 34.0 | 22.0 | 4.3 | 80 | 170 | run |
| 60 | 36.0 | 37.1 | 8.0 | 98 | 152 | start |
| 120 | 36.0 | 37.0 | 4.2 | 98 | 152 | |
| 180 | 35.0 | 32.5 | 2.2 | 118 | 132 | run |
| 240 | 34.0 | 30.0 | 4.0 | 138 | 112 | stopped |

| | |
|---|---|
| Filter run | 4 hours |
| Total volume of water filtered | 5220 lits |
| Rate of filtration | 250 lit/min/m$^2$ |
| Average inf. turbidity (optical) | 32 units |
| Average eff. turbidity (optical) | 4.5 units |
| Average inf. temperature | 35° C |
| Average pH influent | 7.8 |
| Average pH effluent | 7.7 |
| Alkalinity influent | 89 mg/l as $CaCO_3$ |
| Alkalinity effluent | 86 mg/ as $CaCO_3$ |
| Alum dose | 16 mg/lit |

*Head loss at different pressure points*

| Time of operation minutes | Depths below filter surface in cms 2 | 7 | 17 | 27 | 37 | 47 | 57 | 67 | 77 | 87 | 97 | Volume of water filtered | remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 4.9 | 10.0 | 20.6 | 31.4 | 26.4 | 22.2 | 18.8 | 15.0 | 11.2 | 7.5 | 3.9 | 0 | run |
| 60 | 21.5 | 29.0 | 40.6 | 51.5 | 45.0 | 40.4 | 35.6 | 30.5 | 25.5 | 20.2 | 12.4 | 1305 | started |
| 120 | 45.4 | 55.2 | 67.6 | 79.0 | 71.0 | 65.2 | 59.8 | 53.0 | 46.2 | 38.4 | 21.8 | 2610 | |
| 180 | 78.2 | 90.0 | 111.0 | 121.0 | 111.5 | 104.2 | 97.0 | 89.0 | 80.0 | 68.5 | 34.5 | 3915 | |
| 240 | 106.0 | 125.2 | 138.6 | 157.5 | 147.0 | 138.5 | 129.8 | 120.0 | 108.6 | 92.0 | 39.8 | 5220 | run stopped as flow rate decreased |

*Note:* Head loss below 97 cms from the top level of the sand is not very considerable because a 5 cms layer of small gravel was used at the bottom to prevent leaking of sand through the opening between the perspex sheet and the false bottom plate.

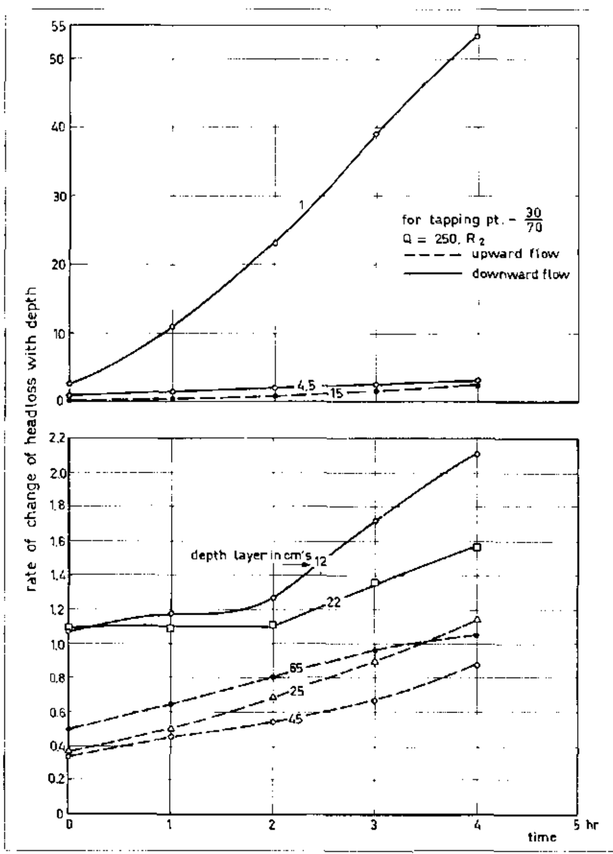
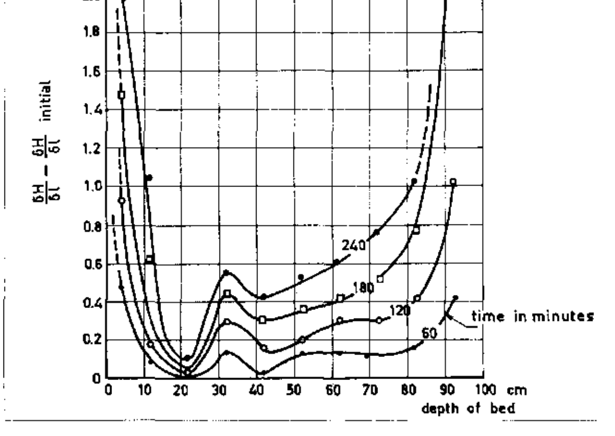


*Fig. 5 - Rate of change of headloss with depth VS time.*

effluent line for measuring total filtration rate and the other installed in the backwash line for measuring upward flow during filtration as well as backwashing rate. The temperature variation of the raw water was found to be between 30-36° C.

The alum dose determination was carried out by jar test.

*Fig. 6 -* $\frac{\sigma H}{\sigma l} - \frac{\sigma H}{\sigma l}$ *initial VS depth of bed.*




pH and alkalinity measurement of both raw water and filtered water was carried out at different stages. Due to the closed circuits system, the resultant decrease of pH and alkalinity was made up by addition of black cotton soil and make up water which also contributed in maintaining desired turbidity.

Conclusion of the experimental results

1. The pattern of head loss closely follows the principle of biflow filtration i.e. filtration through two portions. The nature of head loss curves are similar for all the flow rates. The head loss per unit time is higher for greater flow rates. The head loss per unit dcpth is greater near the top and the bottom entry layers than at the middle (fig. 3 and 4).
2. The flow of water containing alum floc through the filterbed gives a rapid increase in the rate of change of head loss, with respect to the depth, near the top of the bed whereas there is no progressive increase in the middle zones at the different times of run (fig. 5).
3. The distribution of total head loss is more or less uniform throughout the depth of the filterbed with higher rates of flow.
4. A greater yield of filtered water per unit loss of head is obtained at higher filtration rates.
5. The difference of $\frac{\sigma H}{\sigma l} - \frac{\sigma H}{\sigma l}$ (initial) is not appreciable, in regions close to the tapping point, which indicates that this region is not very effective in filtration (fig. 6).
6. The biflow as designed and tested showed good performance for flow rates 150, 200, 250 lit/min/m$^2$, with turbidity removal up to of international standard of 5 units. In almost all cases, the filtrate turbidity was ranging from 2-4 units (optical), which conforms to the standard.
   The effluent turbidity, as compared with the normal gravity filter, seems to be a little higher due to the fact that a mixed quality of effluent is arrived at in a biflow filter, because of filtering simultaneously from below through the bulk of the filter and from above through the top layer of fine sand.
7. For the present set-up, with the uniform size of sand used, tapping points 30/70 seem to be more effective in filtration.
8. The length of the filter run can be increased by proper pretreatment of raw water and use of graded sand for a given flow rate and influent floc concentration.

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