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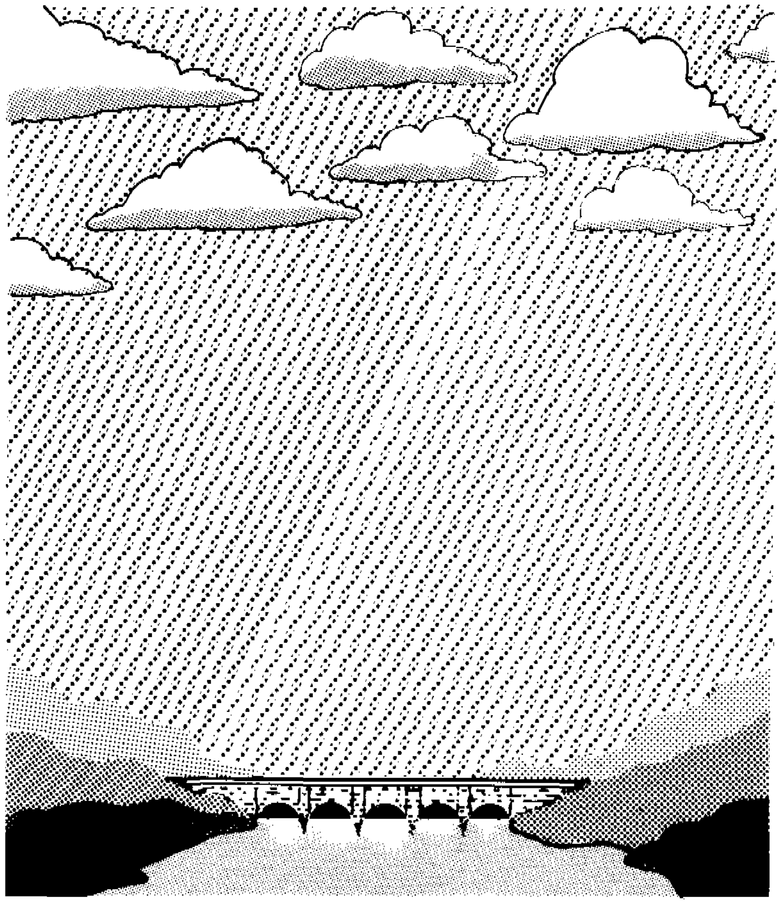

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IMPROVEMENT OF SLOW SAND FILTRATION:

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ABSTRACT

After bibliographic survey on the use of slow sand filtration and particularely about the improvements which could be brought to bear on this technique, a description of a rehabilitation project of a slow sand filtration plant is made. This project concerns a water plant at Ivry which meet 15 percent of water needs for the city of Paris.

INTRODUCTION

Slow sand filtration is one of the most ancient water treatment techniques. Although it had already been described in ancient times, it was only in the 17th, 18th and 19th centuries that the principles of this treatment for making water fit for drinking were dealt with in scientific literature or in the form of patents (1)(2). It was then that these treatment techniques were implemented in major cities to produce drinking water : London (1830), Hamburg (1890), Paris (1898) (2)(3). During the sixties, however, the trend was to replace slow sand filtration by physico-chemical processes known as "rapid filtration". This process needing little space was an advantage in industrialized countries and especially in urban areas. Three key dates explain the renewed interest in biological treatment and slow filtration in particular.

1974 - Rook (4) and others (5) showed the secondary effects of chlorine with organic matter found in water ; this led to the gradual phasing out of the break-point chlorination.

1980 - The UN (6) declared the International Drinking Water Supply and Sanitation Decade open. The only treatment considered reliable and to be recommended for developing countries was slow sand filtration.

1985 - Due to numerous epidemics in the U.S.A., especially giardia cysts, American laws imposed filtration and disinfection as a minimum treatment to be applied to surface water.

This led to renewed interest in slow biological filtration dealt with in a large number of studies conducted at international level. An exhaustive bibliographic survey (6) of all studies concerning this treatment process reveals that it is not outdated and is at least as efficient if not better than physico-chemical processes known as rapid filtration. The most important studies in this area were conducted in

England, France, Germany and the U.S.A. A prospective survey on the future of this type of treatment has even revealed that, since 1975, little new slow sand filtration units have been built or their production capacity has been increased.

In spite of this renewed interest, it is indispensable to understand the reasons why this process was gradually abandoned after the second world war.

TREATMENT PERFORMANCE OF SLOW SAND FILTRATION

Description of the process

Slow sand filtration consists in percolating water through a filtering medium composed of a 0.6 to 1 meter thick sand bed. Sand can have an effective grain size structure varying from 0.15 (in England) to 1 mm (in France). The rates of filtration can vary from 2 to 12 $m.day^{-1}$. After a few days, a complex biocenosis composed of algae, bacteria and zooplankton develops in the top layer of the filtering media. Extremely complex phenomena take place, involving a large number of organisms living in symbiosis and as mutual predators. This biofiltration process must clarify the water and remove organic and mineral micropollutants as well as microorganisms contained in the water to be treated.

Clarification

Clarification consists of removing suspended matter and colloids. As soon as this process was introduced, it was considered extremely efficient for removing and decreasing turbidity. It even served as a reference treatment when physico-chemical processes were first implemented.

Based on the current state of the art, not only can we explain the effect of biological filters on water clarification but we also know the limitations of such filters.

Suspended matter is removed by filter screening. The larger the volume of suspended matter present, the more quickly the filter is clogged. Colloids are neutralized and coagulated by micro-organisms fixed on the sand (algae, bacteria, etc) which secrete polysaccharides. When the turbidity of raw water is too high, not enough polysaccharides are excreted : the filter is clogged quickly and this leads to a high turbidity of the water. It may be considered that water arriving on these filters with a turbidity of more than 10 NTU will not be adequalety treated (turbidity of filtered water not exceeding 1 NTU).

Removal of mineral micropollutants

Mineral micropollutants are removed by precipitation - coprecipitation. Adsorption and bioconcentration exist in physicochemical as well as biological treatments but play a small part in removing mineral micropollutants. Trace elements will therefore be precipitated or coprecipitated either in the form of hydroxides or carbonates, or after an insoluble compound is formed with a reagent added to the water.

Cd, Pb, Hg, Zn, FeIII, MnIV, Al, CrIII, Ni, and Co are removed by the formation of a hydroxide or carbonate and coprecipitation of these compounds. The most important parameters to be considered to ensure removal of such compounds are :

- pH : the more alkaline, the greater is the removal, except in the case of amphoteric elements such as aluminium.

- turbidity of water treated : low turbidity indicates extent of precipitation and coprecipitation.

It has been suggested (7)(8) that the valency of CrVI, MnII and FeII must correspond to their precipitation - coprecipitation in the water to be treated. Hexavalent chromium must be reduced to trivalent state by ferric sulfate. Bivalent iron and manganese may be biologically oxidized to a valency of 3 and 4, respectively, on the biological filters. Oxyanions (arsenates, vanadates, selenates and phosphates) may react with ferric salts (7)(8) to produce insoluble substances which will then be coprecipitated. It is shown that chemical reagents must be added, in the case of the last two groups of compounds, to ensure adequate retention of these groups of elements.

Removal of organic micropollutants

Organic micropolluants may be removed using two different processes :

a) abiotic process : hydrolysis, photolysis, volatilisation, precipitation, coprecipitation, adsorption, oxidation.

b) biotic process : biodegradation, hydrolysis, adsorption, bioconcentration.

In the abiotic process, all elements adsorbed on suspended matter will already be removed. A long retention time in the biological filters facilitates hydrolysis, photolysis and evaporation. It has been proved (10) that the biological membrane has a considerable adsorption capacity in the case of hydrophobic molecules.

In the biotic process, biodegradation is the chief means of degrading organic molecules. We may therefore consider that certain non-biodegradable molecules, which were not retained by abiotic means, may pass through this processing stage.

Removal of micro-organisms

The most recent, as well as the earliest, studies show that this process may be considered as a biological barrier. This is one of the reasons why it was selected for the International Drinking Water Supply and Sanitation Decade (6). Studies carried out in England, Germany and the U.S.A. (6)(11)(12) show that this method was a good means of removing pathogenic bacteria, viruses, giardia cysts and cryptosporidia.

Advantages of slow filtration

According to most studies (2), biological filtration is a reliable method which is not subject to human error since all purification processes are physico-chemical and biological and do not necessitate input or dosing of chemical reagents. The process is increasingly considered as a microbiological barrier for bacteria, viruses and parasites (giardia cysts, cryptosporidia, etc) (11)(12). Low filtration speeds (0.1 to 0.5 mh^{-1}) result in a considerable water storage (3 to 4 h) making it possible, in case of accidental pollution of short duration, to cease supplying the plant with raw water without modifying delivery. Furthermore, this mass of water constitutes significant buffer. A good removal of assimilable organic carbon has been observed.

Disavantages of slow filtration

The different problems to slow filtration are as follows :

- does not allow excessive turbidity.

- it is difficult to remove certain mineral micropollutants requiring an emergency reagent.

- it is difficult to eliminate certain organic micropollutants which must be removed by an emergency reagent or which may escape treatment or be generated by the treatment itself.

- excessive proliferation of algae in the summer.

Nevertheless we decided to continue the slow sand filtration in Paris and we have thougt about the improvements to be made either upstream or downstream of biological filters. An application is described here.

DESCRIPTION OF TREATMENT PLANT

Ivry plant is located on the river Seine upstream. This plant supplies approximately 15 percent of drinking water consumed in the city of Paris. This is an extremely important plant for Paris because it is the only plant which can supply all sections of Paris.

Description of the current network

Raw water is pumped from the Seine, screened and then passed through two filtration stages (one known as roughing filtration and the other as prior filtration) before reaching the biological filters. Ozonisation is then carried out virucidally and the water is disinfected by chlorine before being fed into the Parisian network (figure 1). The Ivry plant has a treatment capacity of 175 000 m^3 for distributing good quality water. Annual output is 45 000 000 m^3. A project of renovation of the process of water treatment is thought in order to ensure reliability as regards the quantity and quality of water produced, bearing in mind the various currently applicable or future standards : EEC guidelines (13)(14) WHO guidelines (15) and future French standards (16).

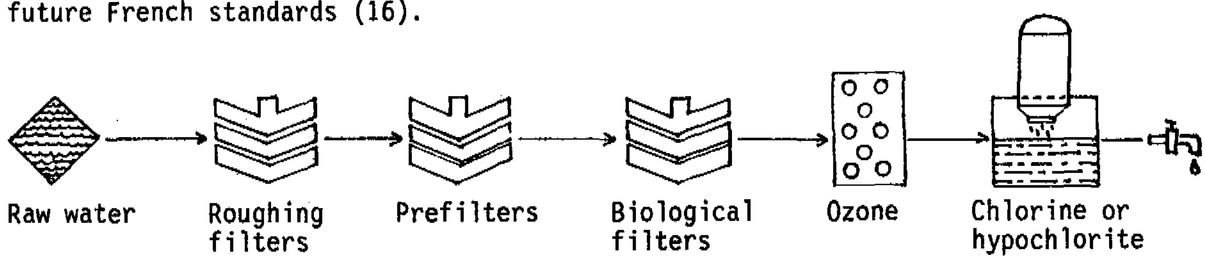


Figure 1 : Current Ivry treatment flow sheet.

Quality of raw water at water intake

Over the past ten years, the quality of raw water has increased significantly with regard to background micropollution.

A comparison (17) between current findings and results obtained some years ago reveals that, concerning mineral micropollutants, raw water has progressed from class A3 in 1980 to class A1 (13) in 1986. This improvement is due to the increased efficiency of the Agence de Bassin Seine-Normandie whose pollution control policy prompted a significant drop in direct river discharges (water treatment works at Valenton). It is also due to a decrease in the number of small industries along the Seine which used to discharge wastes directly without any prior treatment. Organic micropollution is always present and we must devise a means of reducing it within the framework of the Ivry plant rehabilitation project. The new guidelines (WHO, EEC, French) have shown that we have to improve water quality upflowing from Ivry.

Accidental pollution is a problem which is common to all water treatment works. Average plant shutdown time due to accidental pollution over the past ten years is 2.5 days per year : a network of warning stations has been set up by the Seine to improve information transmission speed. These stations constantly detect the most important parameters concerning pollution and may trigger off alarms if an abnormal concentration is detected. The stations are situated above the water intake and a warning station will be set at 1,6 km upstream. This allows intervention within 30 minutes in the event of pollution and enables rapid input of emergency reagents, for example, if necessary.

Water quality problems in relation to the current network at the Ivry plant

In addition to shutdowns due to pollution, the Ivry plant must cease or slow down water production in the event of excessive turbidity in the Seine (attaining up to 100 NTU).

The figure 2 shows us the evolution of the turbidity on the past ten years. This curve is an adjustement with a log normal law of the turbidity and we can say that only 5 % of the measured turbidities during the last ten years (18) are over 60 NTU.

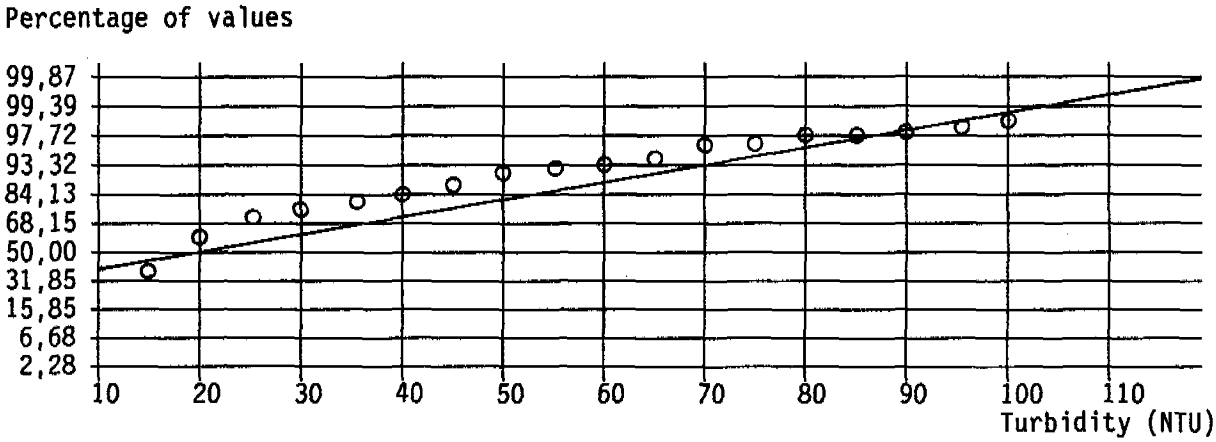


Figure 2 : Statistical representation of turbidities of raw water during the last ten years.

Nevertheless, we considered it was indispensable to improve two aspects in particular at the Ivry network :

- upstream improvement of biological filters so as to avoid in all the cases turbidity peaks noted and which may therefore protect the biological filters particularely against accidental pollution,

- downstream improvement so as to enhance the quality of water, especially concerning organic micropollution to reduce, as far as possible, any changes in quality during distribution, and to remove some compounds which could be produced by slow sand filtration. One may therefore consider (18) that a raw water turbidity of more than 30 to 40 NTU is the maximum which may be treated at these preliminary stages to ensure that the water reaches the biological filters with a turbidity of 10 NTU.

PROPOSED PRETREATMENT FOR SLOW SAND FILTRATION

The main arm of this pretreatment is to produce a stabilization of turbidity at the lowest possible value before biological filters and to have the possibility of using emercengy regents.

We have considered four different possibilities of pretreatment being effective to remove especially turbidity :

- storage reservoir
- coagulation floculation sedimentation filtration
- coagulation filtration
- contact coagulation coagulation of filter.

Our twenty-five years of experience at another plant supplying the city of Paris (the Saint-Maur plant) and previous studies on combined physico-chemical and biological treatment (19) at the Saint-Maur pilot plant served as a basis for devising a new treatment.

In the Saint-Maur plant, water treatment consist of slow sand filtration but raw water flows in a 671 meters long canal before flowing on prefilters : so, when the turbidity of raw water increases, ferric chlorid (10 - 20 $mg.l^{-1}$) is injected at the head of this canal and a sort of coagulation - flocculation - sedimentation takes place, the quality of water inflowing on biological filters being improved. Pilot plant studies (19) have been conducted at St-Maur plant on a pilot which combined a physicochemical treatment (coagulation - floculation - děcantation - rapid filtration) and a biological treatment (slow sand filtration). This treatment is very effectiveness (19) but we use a lot of reagents and we have imagined another pretreatment in view of a preserving the structure of Ivry plant : a contact coagulation followed by coagulation on filter. This type of treatment has been known since 1979 but, to date, it has only been used for low turbidities (12)(20)(21). A recent American study shows that this process is superior to rapid filtration treatments for removing giardia cysts. (12)

Principles of contact coagulation - coagulation on filter

Contact coagulation - coagulation on filter is carried out on two different works which are filters, with each work playing a special role. A small quantity of coagulant (e.g. ferric chloride) is added before the first filter. The usual dose is 1/5 or 1/10 of the optimal dose necessary in the case of physico-chemical treatment comprising coagulation - flocculation - sedimentation - rapid filtration. The first filter uses a high granulometry (effective size > 2 mm) medium, thus forcing the water to pass between the grains and causing partially neutralized colloids to agglutinate and flocculate. This incoherent floc is filtered on the second filter which has a lower granulometry (effective size = 0.95), thereby initiating a coagulation process on this filter. The first filtration stage diminishes raw water turbidity and has a certain buffering action. This allows good coagulation at the second filtration stage. After this preliminaty treatment, we believe the water may have a turbidity of less than 10 NTU which is suitable for the proper operation of slow biological filters. In order to verify this theory, tests of contact coagulation - coagulation on filter were carried out.

PILOT PLANT TEST

Tests were carried out at the Ivry plant with its current structure.

First filtration stage
- gravel 30 cm high
- effective size : 12 mm
- filtration rate is about 3 $m.h^{-1}$ at the plant's current normal production rate.

Second filtration stage
- gravel 60 cm high
- effective size : 0.95 mm
- filtration rate is about 2 $m.h^{-1}$ at the plant's normal production rate.

Ferric chloride was added to the raw water channel of approach at a point enabling an immediate and homogeneous mixture. Figure 3 gives a detailed view of plant facilities.

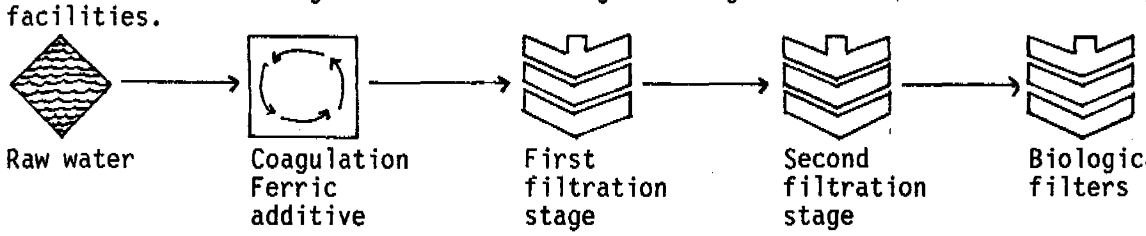


Figure 3 : Detailed wiew of plant facilities.

	5 g.m^{-3}			7,5 g.m^{-3}			10 g.m^{-3}		
	Raw	Préfiltered Without additive Fe	Préfiltred with additive Fe	Raw	Préfiltered Without additive Fe	Préfiltred with additive Fe	Raw	Préfiltered Without additive Fe	Préfiltred with additive Fe
Turbidity NTU	7,2	1,28	0,92	12,1	1,3	1,1	30,6	3,3	1,7
Oxydability KMn04 mg/l O2	4,35	2,38	1,97	4,56	2,30	1,98	4,94	2,76	1,86
Ammonium mg/l NH4	0,69	0,11	0,04	0,68	0,072	0,035	0,45	0,072	0,05
Nitrites mg/l NO2	0,24	0,15	0,085	0,26	0,10	0,072	0,21	0,085	0,08
Phosphates mg/l PO4≡	1,28	0,96	0,60	0,94	0,94	0,55	0,84	0,77	0,30
TOC mg/l C	3,6	2,63	2,26	5,12	2,38	2,02	4,92	3,29	2,49

Table 1 : Results of tests of contact coagulation - coagulation on filter, according to the dose of ferric chloride

Optimization tests for ferric chloride dosing

As we have said, the dose of coagulant used with this process is 1/5 to 1/10 of the optimal dose needed for a physicochemical treatment. We studied three concentrations (5, 7 and 10 $g.m^{-3}$), the optimal dosage for a physicochemical treatment being 50 $g.m^{-3}$ for the studied period. Results are presented in the table 1 (means on the results on ten days with two determinations per day).

The following conclusions may be drawn from these findings :

- during the test period, raw water turbidity gradually increased from 7 to 30 NTU ;

- a beneficial effect was obtained for all parameters examined (turbidity, permanganate oxidation, NH4, NO2, PO4, COT)with a coagulant additive. The 5 ppm dosing seems to be quite sufficient for all parameters.

- two phenomena must be noted concerning turbidity : increase in turbidity in raw water and an increase in coagulant dose.

It is therefore clear that differences are not signifiant.

As a result, we considered 10 ppm of ferric chloride to be satisfactory.

Comparison of the results obtained with this pretreatment with the results obtained with the actual process

Tests have been conducted on the whole station and we can compare two periods where the quality of the water was the same.

- one period without ferric chloride pretreatment,
- one period with the pretreatment of contact coagulation coagulation on filters.

Results are presented tab. 2.

	Prefiltered water		Filtered water	
	With addition of Fe during pretreatment	Without Fe	With addition of Fe during pretreatment	Without Fe
Turbidity NTU	88,5	87,5	99,5	95
Oxydability mg/l O2	42,5	30	67,0	48
Ammonium NH4 mg/l	86,0	91,5	100	100
Nitrite mg/l NO2	86,5	81,5	100	100
Phosphates mg/l PO4*	81	17	85	17
Iron mg/l Fe	87	89	100	100
TOC mg/l C	42	26	42	42

Table 2 : Comparison between reduction rates in relation to raw water.

The results show a better removal of turbidity, oxydability and phosphates with this pretreatment. As it has been shown before, the usefulness of this pretreatment is particularly important when the turbidity of raw water increases.

Tests conducted according to the temperatures

It has seemed interesting to test the effectiveness of this pretreatment during periods where the temperature of raw water varies : as a matter of fact, the nature of the turbidity, of the oxidability varies with the seasons. In winter, waters are very turbid and colloids present in water are mainly due to clays. In opposite during warm seasons, turbidity and oxidability originate from humic acids particularly.

Results are presented tab. 3 and tab. 4.

	Raw water	Prefiltered water	Filtered water
Turbidity NTU	14,8	0,88	0,25
pH	8,1	7,80	7,85
Oxydability mg/l O2	3,37	1,94	1,29
Ammonium NH4 mg/l	0,30	0,036	< 0,02
Nitrite mg/l NO2	0,11	0,03	< 0,01
Phosphates mg/l PO4 ≡	0,68	0,33	0,33
Iron mg/l Fe	0,24 + 1,4*	0,025	< 0,02
TOC mg/l C	4,4	2,47	1,6

* 1,4 mg/l corresponds to the quantity of iron added by treatment.

Table 3 : Average results for contact coagulation - coagulation on filter tests during the warm season.

	Raw water	Treated water	Filtered water
Turbidity NTU	41	4,7	0,25
pH	8,23	7,96	7,91
Oxydability Mg/l O2	8,45	4,88	3,62
Ammonium NH4 mg/l	0,13	0,018	< 0,01
Nitrite mg/l NO2	0,12	0,016	< 0,01
Phosphates mg/l PO4≡	0,84	0,16	0,126
Iron mg/l Fe	0,91 + 1,4 *	0,3	< 0,02
TOC mg/l C	6,72	3,9	3,9

* 1,4 mg/l corresponds to the quantity of iron added by the treatment.

Table 4 : Average results for contact coagulation - coagulation on filter tests during the cold season.

DISCUSSION

For all parameters, there is no difference in efficiency of pretreatment stage between warm and cold season. The findings from the first tests are confirmed :

- reduction in turbidity after contact coagulation - coagulation on filter,
- reduction in organic matter measured by $KMnO^4$ oxidability, TOC
- decrease in phosphate content of the water.

Nevertheless efficiency of biological filtered water is different for three parameters : TOC, oxidability and phosphates. These results are new with regard to the actual process of treatment. Concerning oxidability, there is no difference between the warm and cold season as regards removal. Elimination of total organic carbon during the warm season is comparable to that of oxidability, whereas this is not the case during the cold season. One explanation is that, during the warm season, biodegradation of molecules leads to their elimination. This explains a concomitant decrease in oxidability and organic carbon. In winter, biodegradation would lead to the formation of oxidized organic molecules causing a fall in the reducing power of waters without decreasing total organic carbon. Removal of phosphates during the warm season is not as good as during the cold season. We have shown in previous studies that phosphates are removed from the water by reaction with ferric ions because they form an insoluble ferric phosphate which is retained by the treatment. This removal increases as the quantity of iron present in the water increases. The initial quantity of iron in the raw water (8) must therefore be taken into consideration. This gives us 0.24 + 1.4 (added in the form of $FeCl3$) = 1.64 $mg.l^{-1}$ during the warm season and 0.91 + 1.4 (added in the form of $FeCl3$) = 2.31 $mg.l^{-1}$ during the cold season. This explains the difference noted.

The findings of these three test on the different periods were as follows :

1) a 10 $mg.l^{-1}$ ferric chloride dosing enhances the plant's realiability as regards high turbidity ;

2) elimination of turbidity was also accompanied by improved removal of organic matters and phosphates.

3) washing of pretreatment stages was facilitated in spite of the fact that a coagulant was added.

This pretreatment seems very effective and the test carried out at the Ivry plant allowed us to make a clear-cut classification of the different possibilities in the field of water pretreatment. Table 5 shows that bearing in mind the problems to be solved (high turbidity, the need to be able to add emergency reagents in case of accidental pollution, need to reduce algae proliferation) the only suitable treatments are rapid filtration or dual stage filtration (contact coagulation - coagulation on filter).

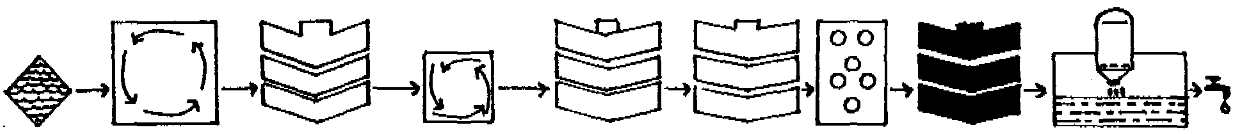
	Storage reservoir	Coagulation flocculation sedimentation filtration	Coagulation filtration	Contact coagulation coagulation on filtre
Advantages :				
Buffering action	X			
Pollution security	X			
Turbidité removal	X	X	X	X
Toxicity removal		X	X	X
Emergency reagents		X	X	X
Automation	X	X	X	X
Chemical reagents			X	X
Operating costs			X	X
Flexibility			X	X
Passivity			X	X
Disadvantages :				
Algae problems	X			
Space	X			
Chemical reagents		X		
Sludge treatment		X		
High turbidity			X	(X)

Table 5 : Summary of the avantages and disavantages of the different pretreatment stages prior to biological filtration.

CONCLUSION

Tests carried out at the Ivry plant have shown the effectiveness of a pretreatment (contact coagulation - coagulation on filter). On the other hand the Ivry plant rehabilitation project takes into consideration the improvement of the quality of water and the removal of organic micropollution in particular. Furthermore, as pointed out before, some metabolites may be generated by biological filtration and we believe that it is important to be able to remove them. It is now acknowledged (22) that the combined use of ozone and granular activated carbon is very efficient in removing organic matter. Post-ozonization was eliminated in certain countries such as England and Belgium as it was not followed by filtration on activated carbon. These countries considered that activated carbon was redundant when biological filters were used.

We consider that these two stages (ozone - activated carbon filtration) allow for very good water purification and may therefore avoid bacterial post-proliferation. All this enabled us to design a new flow sheet (fig 4) for Ivry plant including :



Raw Water — Coagulation Ferric chloride additive — First Filtration stage — Ferric Chloride possibly — Second Filtration stage — Slow sand filter — Ozone — GAC Asorption — Chlorine gas or hypochlorite

Figure 4 : New treatment flow sheet.

- pretreatment by contact coagulation followed by coagulation on filter with addition of ferric chlorid (5 to 10 $mg.l^{-1}$ depending on the turbidity of raw water). The respectives rates of filtration will be 8 to 10 $m.h^{-1}$ on the first stage and at 5 to 8 $m.h^{-1}$ on the second stage ;

- slow sand filtration at a rate of 5 to 10 $m.day^{-1}$;

- ozonization ;

- filtration on granular activated carbon with a water-carbon contact time of 6 to 15 minutes, depending on plant operation ;

- final desinfection with chlorine or sodium hypochlorite.

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