Coagulation/flocculation of domestic sewage with organic Polyelectrolytes

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The removal of organic particles present in domestic sewage can be increased by coagulation/flocculation process as compared to the application of primary sedimentation tank, which only depends on plain settling. The aim of the present work is to study the effect of the variables affecting the removal efficiency of organic matter present in domestic sewage using a jar testing apparatus. Variables studied were, type and dose of flocculent/coagulant, G- value, rapid mixing, settling and flocculation time. The results showed that cationic Polyelectrolytes C-492 HMW and C-492 MMW can efficiently remove turbidity as high as 75% with doses as low as 10 mg/l. With application of C-581 and $FeCl_3$, high doses of 50 mg/l and 25 mg/l were needed respectively. The results showed that decreasing settling time from 900 to 120 sec and flocculation time from 180 to 30 sec respectively did not affect the turbidity removal with Polyelectrolyte C-492 HMW. However, in case of rapid mixing, time played an important role in turbidity removal. The turbidity removal values were about 67 and 75% at rapid mixing time of 30 sec and G-value of 800 sec^{-1} respectively by C-492 HMW. Removal of total COD was about 52 %, while removal of total phosphorous and total Kjeldahl nitrogen were 29 and 30%, respectively.

تلعب البوليمرات الإلكتروليتية دورا هاما فى تنقية مياه الشرب ومعالجة سوائل الصرف الصحي والصناعي . يمكن زيادة إزالـــة المواد العضوية المعلقة الموجودة فى سوائل الصرف الصحى بإستخدام البوليمرات الإلكتروليتية العضوية . ولقد تـــم فـــي هـــذا البحث دراسة العوامل المؤثرة على عمليات الترويب / التجلط مثل نوع المروب (حيث استخدمت أربعـــة أنـــواع مختلفـــة مـــن البوليمرات الإلكتروليتية العضوية مقارنة مع كلوريد الحديديك كمروب غير عضوي) وكذلك تم دراسة ســـرعة الخلـــط وزمـــن الترسيب . ولقد أظهرت النتائج أنه يمكن إزالة حوالى ٧٥% من العكارة باستخدام البولى الكترو ليـــت (C-492 HMW) باستخدام جرعة مقدارها ١٠ مج/لتر ، كما أنه أمكن خفض زمن الترسيب من ٩٠٠ الى ١٢٠ ثانية وكذلك الزمن اللازم لعمليـــة الترويب من ١٨٠ إلى ٣٠ ثانية ، بالإضافة إلى ذلك فانه أمكن إزالة حوالى ٥٢ % من الأكسيجين الكيميائى الممتص إضافة الـــى إزالة ٣٠ % من النتروجين ، ٢٩ % من الفوسفور.

Keywords: Domestic sewage, Coagulation, Flocculation, Settling, Rapid mixing

1. Introduction

Physical-chemical pretreatment is based on the separation of suspended and colloidal particles from wastewater. A good particle separation is important in wastewater treatment, since a major part of the influent COD consists of particulate material. Measurements on several influents showed that approximately 70 % of COD is in particles > 0.45 μm and many pollutants are partly incorporated into particulate material (e.g. nitrogen, phosphorous) or adsorbed onto particulate material (e.g. heavy metals, organic micro-pollutants). As a result of physical-chemical pretreatment, a lower load of pollutants is left for removal by post-treatment, so this step can be designed to be more energy efficient and more compact [1,2].

STOWA [3], Van Nieuwenhuijzen et al. [4] and Mels et al. [5] found that through advanced particle removal by physical-chemical pretreatment, wastewater plants can become more energy efficient and can be designed significantly smaller. The treatment scenarios, which are based on physical-chemical pretreatment, do not have to be more expensive than commonly used treatment systems, especially when biological post treatment is not applied.

Traditionally coagulants/ flocculents used in wastewater treatment are inorganic metal salts like ferric chloride and aluminum sulfate. This is partly due to the fact that metal salts can also remove ortho-phosphate by precipitation. However, when these metal salts are used, high quantities of chemical sludge are produced. With addition of organic coagulants (Polyelectrolytes), the production of chemical sludge can be reduced considerably without affecting suspended solid (SS) removal [6]. The sludge volume was about tenth (1/10) of the volume resulting from coagulation by aluminum sulfate [7].

This paper describes the application of Polyelectrolytes for domestic sewage pretreatment. The objectives of this work were:
1. to study the effect of five different coagulants/flocculents on turbidity removal,
2. to investigate the effect of rapid mixing, flocculation and settling conditions on the turbidity removal, COD and nutrients removal by a high molecular weight cationic Polyelectrolyte (C-492 HMW).

2. Materials and methods

2.1. Jar testing apparatus

Batch experiments were conducted in a set-up with 6 beakers of 2.5 liters fig. 1. Each beaker was filled with 2.0 liters of wastewater. Coagulants/flocculents were dosed simultaneously to all beakers at intensive mixing conditions. After rapid mixing at a certain velocity gradient (G-value), slow mixing for flocculation was applied. After a certain period of flocculation mixing a period of no mixing was applied in order to allow the formed flocs to settle.

2.2. Polyelectrolytes

For coagulation/flocculation linear Polyelectrolytes based on polyacrylamides were used. Also $FeCl_3$ was used in one of the experiments. Table 1 gives an overview of the Polyelectrolytes which were used in the experiments.

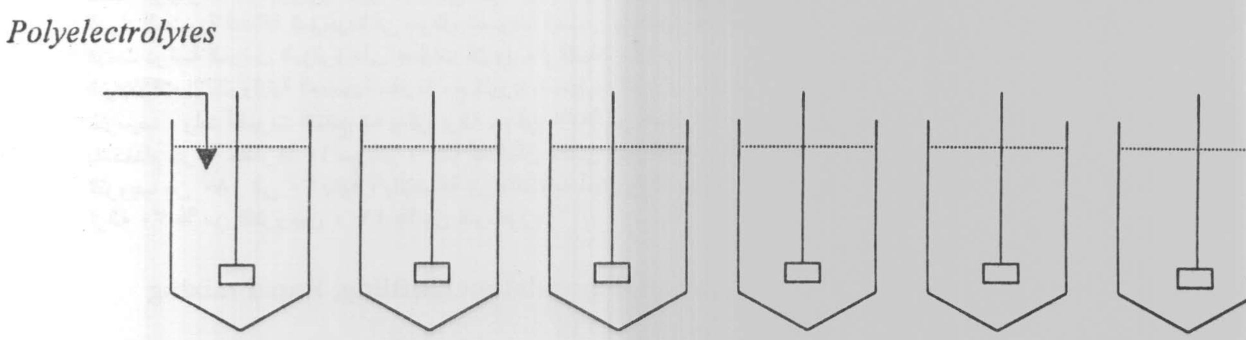

Fig. 1. Experimental set-up.

Table 1
Overview of Polyelectrolytes* which were used in the experiments

Description	Characteristics	Product
High molecular weight cationic flocculent	8×10^6 g/g. mol; charge 24 weight %	SF C-492 HMW
Mid molecular weight cationic flocculent	6×10^6 g/g. mol; charge 24 weight %	SF C-492 MMW
Low molecular weight cationic flocculent	4×10^6 g/g. mol; charge 24 weight %	SF C-442 LMW
Cationic coagulant	2.5×10^5 g/g. mol	SF C-581
Anionic flocculent	10.5×10^6 g /g. mol;charge 20 weight %	SF A-110 MMW
Ferric chloride	$FeCl_3 . 6H_20$ (MERCK)	

* CYTEC Industries B.V., Botlekweg 175, 3197 KA Botlek- Rotterdam, The Netherlands

2.3 Wastewater

Wastewater from the wastewater treatment plant of the Bennekom village (The Netherlands) was used in the experiments. Table 2 shows the characteristics of the wastewater.

Table 2
Characteristics of the wastewater used in the experiments

		Average	Range
Turbidity	(NTU)	164	130 - 185
COD_{total} *	(mg/l)	732	961 - 476
$COD_{suspended}$	(mg/l)	314	469 - 141
$COD_{colloidal}$	(mg/l)	203	307 - 149
$COD_{dissolved}$	(mg/l)	215	125 - 249
$COD_{particulate}$	(mg/l)	517	351 - 648
P_{total}	(mg/l)	11.1	8.5 - 13
P_{ortho}	(mg/l)	6.3	4.8 - 8
$N_{Kjeldahl}$	(mg/l)	57.3	49 - 65
NH_4^+	(mg/l)	39.5	37 – 50
pH		7.7	7.3 - 8.2
Temperature		18.6	15.5 - 21.5

* $COD_{suspended}$ > 4.4 μm; $COD_{colloidal}$ 0.45 – 4.4 μm; $COD_{dissolved}$ < 0.45 μm; $COD_{particulate}$ > 0.45 μm

2.4. Analytical methods

COD was measured using the micro-method described by Jirka and Carter [8]. Raw samples were used for COD_{total}, 4.4 μm folded paper-filtered (Schleicher & Schuell 5951/2) samples for COD_f and 0.45 μm membrane-filtered (Schleicher & Schuell ME 25) samples for dissolved COD. The $COD_{suspended}$ and $COD_{colloidal}$ were calculated by the differences between COD_{total} and COD_f, COD_f and $COD_{dissolved}$, respectively. The nitrogen Kjeldahl was measured according to the *Dutch Standard Normalised Methods* [9]. Total Phosphate for wastewater was measured with an auto analyser Skalar after treatment according to the *Dutch Standard Normalised Methods* [9], while ortho Phosphate was directly measured with the same auto analyser. Turbidity was measured using a nephelometer calibrated turbidimeter measures in nephelometric turbidity units (NTU), Hach model 2100A.

3. Results and discussion

The following parameters were varied in a series of jar tests; type and dose of flocculent/coagulant, G- value, rapid mixing time, flocculation and settling time. The observed parameter were, turbidity, COD, total Kjeldhal nitrogen and total phosphorous.

3.1. Effect of flocculent/coagulant type on turbidity removal

Fig. 2 group shows the turbidity removal by different flocculents. Fig. 2-a illustrates a comparison of three cationic Polyelectrolytes (C-492 HMW, C-492 MMW and C-442 L) which have different molecular weight as shown in table 1. It is clear from this figure that, both C-492 HMW and C-492 MMW have no significant difference as regarding turbidity removal efficiencies, while the removal of the turbidity by C- 442 LMW is lower. The results showed that cationic C- 492 HMW and C-492 MMW can efficiently remove turbidity to about 75% by using a dose of 10 mg/l. Fig. 2-b shows that, when the cationic coagulant (C-581) was combined with 2 mg/l of flocculent A-110 MMW, there was a slight turbidity removal by using lower doses (up to30 mg/l). A sudden increase in turbidity removal was noticed at doses higher than 30 mg/l and about 75% of turbidity were removed by using a dose of 50 mg/l. The results shown in fig. 2-c indicate that when the ferric chloride was combined with a 2 mg/l of flocculent A-110 MMW, a gradual increase in turbidity removal has occurred, and about 70% of turbidity was removed by using a dose of 25 mg/l (as Fe^{3+}). From the previous discussion of results, it is clear that, better turbidity removal was obtained at a small dose (10mg/l) of Polyelectrolytes C-492 HMW and C-492 MMW.

3.2. Effect of settling, flocculation and rapid mixing time on turbidity removal

It is clear from fig. 3 that, the decrease of settling time from 900 sec to 120 sec does not affect the turbidity removal. On addition of Polyelectrolyte C-492 HMW, flocs were formed by flocculation. It was noticed from visual observation that the formed flocs were settled with a moderate velocity [6].

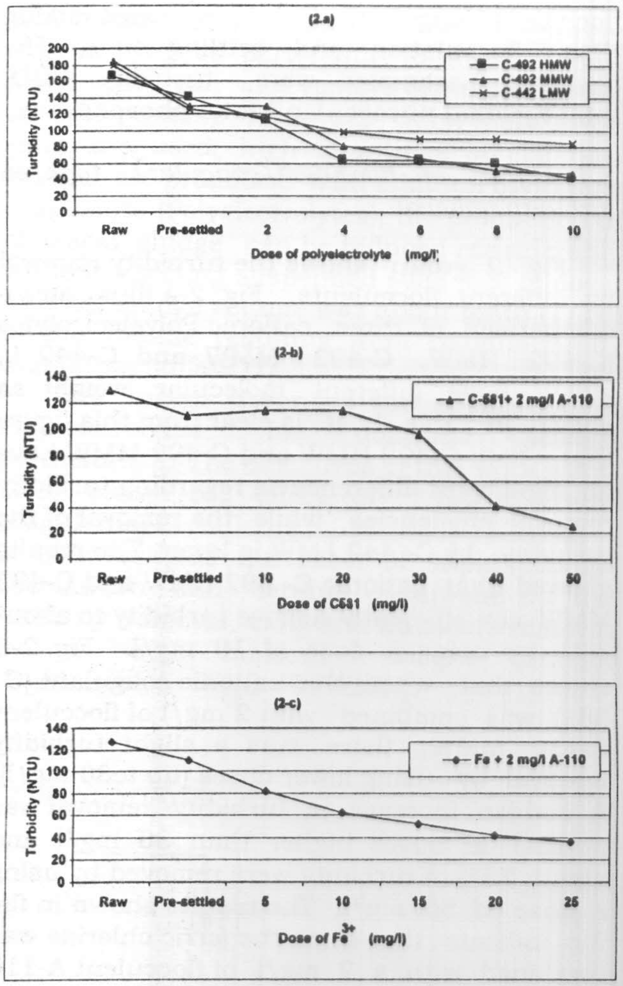

Fig. 2. Effect of different flocculents concentration on the turbidity removal at rapid mixing time = 20 sec, flocculation time = 180 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

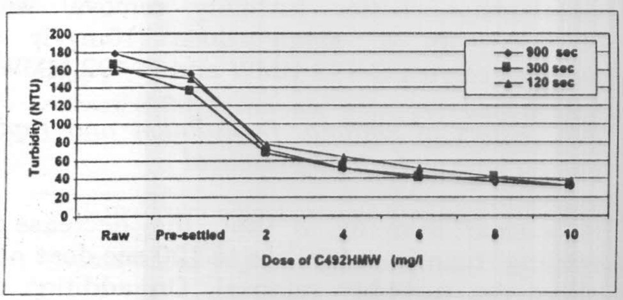

Fig. 3. Effect of settling time on the turbidity removal at rapid mixing time = 20 sec, flocculation time = 180 sec and G-value = 800 sec^{-1}.

Flocculation time was varied from 180 to 0 sec. As shown in fig. 4 group, turbidity removal efficiency is not affected by flocculation time.

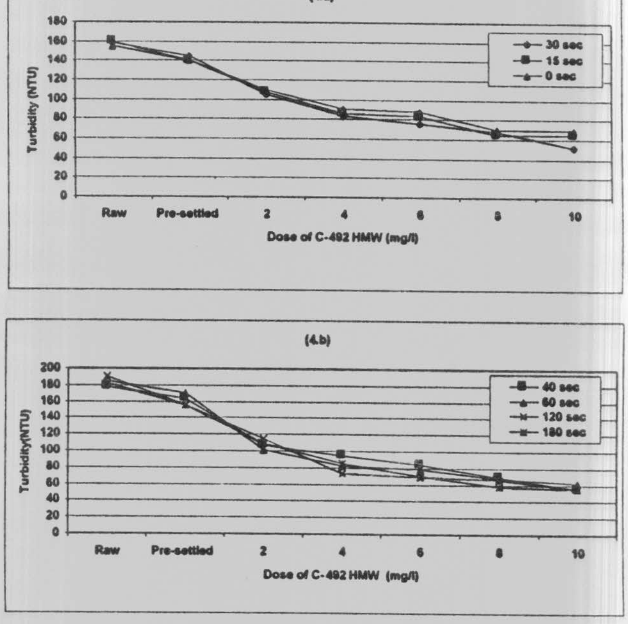

Fig. 4. Effect of flocculation time on the turbidity removal at rapid mixing time = 20 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

The rapid mixing time is an important factor for the flocculation process. Rapid mixing time was varied from 40 to 1 sec. As shown in fig. 5 group, a significant improvement in turbidity removal was achieved with increasing time of rapid mixing. Maximum turbidity removal (67%) was obtained at 30-sec rapid mixing (the same result at 40 sec). The turbidity removal at a rapid mixing time of 1 sec was about 40 % by using a dose of 10 mg/l.

It is clear from fig. 6 that, G-value is also an important factor. G-value was varied from 175 to 1000 sec^{-1}. The increase of G- value increases the turbidity removal efficiency. The results demonstrate that, about 75% of turbidity was removed by the Polyelectrolyte C-492 HMW (dose = 10 mg/l) at G-value of 800 sec^{-1}.

3.3. Effect of Polyelectrolyte addition on COD and nutrients removal

As shown in fig. 7 removal efficiency of total COD was affected by dose of

Polyelectrolyte C-492 HMW. Maximum removal of COD_{total} was about 52%. It is clear from this figure that, for removal of suspended COD a low dose is needed (2 mg/l), while for the removal of $COD_{colloidal}$ a higher dose is needed (10mg/l).

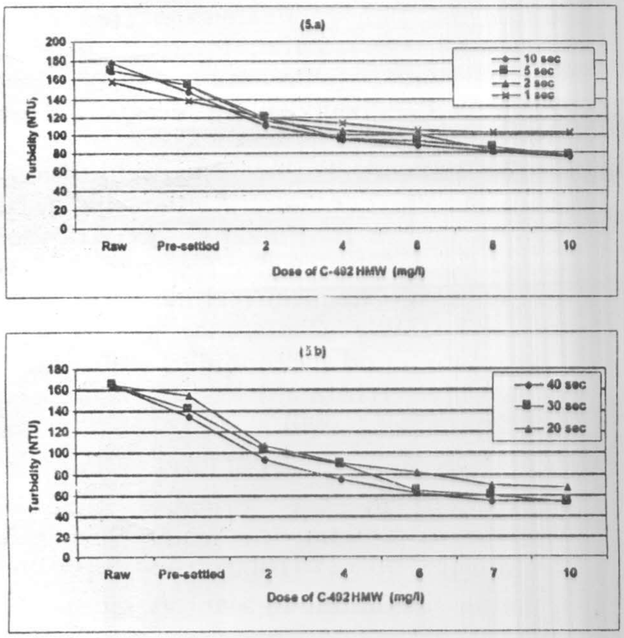

Fig. 5. Effect of rapid mixing time on the turbidity removal at flocculation time = 180 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

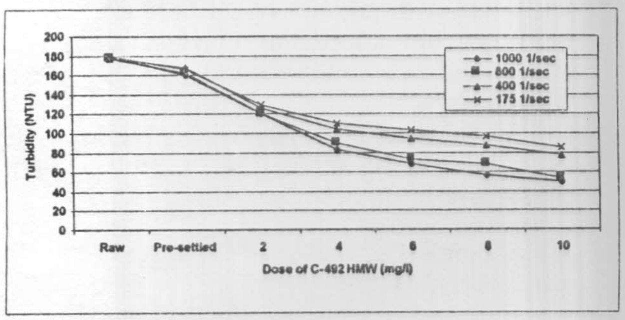

Fig. 6. Effect of G-value on the turbidity removal at rapid mixing time = 20 sec, flocculation time = 180 sec and settling time = 900 sec.

It is clear from fig. 8 that, total Kjeldahl nitrogen removal increases with increasing Polyelectrolyte dose. A removal of 30% for total $N_{kjeldahl}$ was achieved at a dose (10 mg/l) of Polyelectrolyte C-492 HMW

As shown in fig. 9 removal efficiency of total phosphorous is affected by dose of Polyelectrolyte. A removal of 29% for total phosphorous can be achieved at 10 mg/l of Polyelectrolyte C-492 HMW. The amount of phosphorous removed by Polyelectrolyte is probably due to particulate phosphorous, while dissolved phosphorous (ortho phosphorous) can not be precipitated [7].

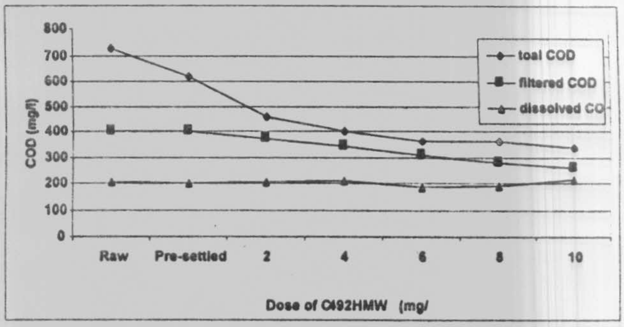

Fig. 7. Effect of Polyelectrolyte (C-492 HMW) dose on the removal of COD fraction at rapid mixing time = 20 sec, flocculation time = 180 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

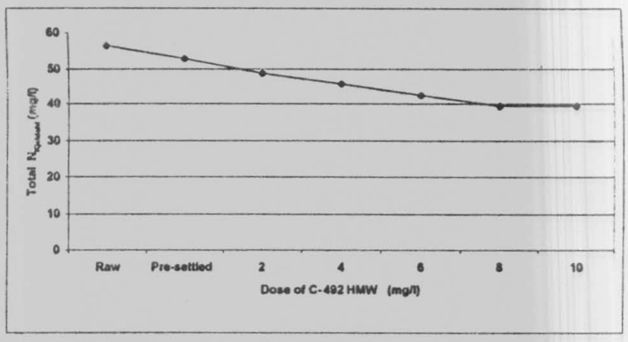

Fig. 8. Effect of Polyelectrolyte (C-492 HMW) dose on the nitrogen removal at rapid mixing time = 20 sec, flocculation time = 180 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

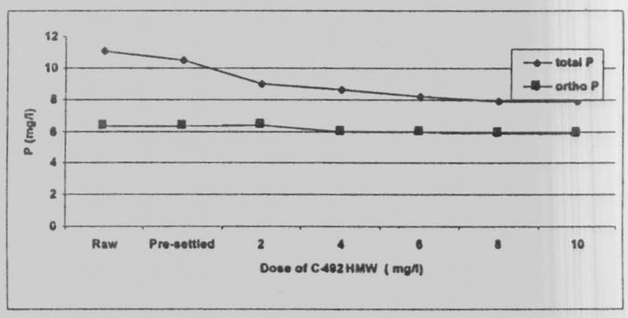

Fig. 9. Effect of Polyelectrolyte (C-492 HMW) dose on the total and soluble phosphate at rapid mixing time = 20 sec, flocculation time = 180 sec, settling time = 900 sec and G-value = 800 sec^{-1}.

4. Conclusions

1. Cationic Polyelectrolyte C-492 HMW and C-492 MMW are efficient primary flocculents for sewage treatment with respect to turbidity and COD removal.
2. Removal of turbidity is about 75% by using C-492 HMW or C-492 MMW (dose =10 mg/l), while removal values are about 75 and 70% by using C-581 (dose=50 mg/l) and ferric chloride (dose=25 mg/l), respectively.
3. Decreasing settling time from 900 to 120 sec and flocculation time from 180 to 30 sec have no effect on turbidity removal.
4. The turbidity removal values are about 67 and 40% at rapid mixing time of 30 and 1 sec, respectively, by Polyelectrolyte C-492 HMW (dose=10mg/l).
5. Removal of turbidity is about 75% at 800 sec^{-1} G-value.
6. Removal of total COD is about 52%, while removal of total Kjeldahl nitrogen and phosphorous are about 30 and 29%, respectively, by using a dose of 10 mg/l of C-492 HMW.

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