PHOTODEGRADATION OF PHARMACEUTICAL PRODUCT (IBUPROFEN) IN AQUEOUS MEDIUM BY PHOTO-LIKE-FENTON PROCESS UNDER NATURAL AND ARTIFICIAL IRRADIATION

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Abstract

In this work, we are interested in the study of the photochemical degradation of Ibuprofen, the active substance of many drugs, by an organic complex (Fe(III) -Malonate) in aqueous solution by the photo like Fenton process using the system (Fe (III)-Malonate complex / H_2O_2 / UV at 365 nm). The results obtained showed a very rapid reaction for the ratio $[H_2O_2]_0$ / $[Fe^{3+}]_0$ = 1/3, at pH = 2.8 and 4.8, and [IBP] = 5. 10^{-5} M, this can be explained by $CH_2COOH^{\cdot}$ [1-2] and $OH^{\cdot}$ [3] The radicals generated by the reaction between Fe^{3+} and H_2O_2 which would come from the free Malonate / Fe (III) complex equilibrium. Furthermore, the study of the IBP-Fe (III) Malonate-H_2O_2 system has shown that Ibuprofen (5.10^{-5} M) disappears more quickly due to the intervention of like Fenton. Natural irradiation tests have shown more rapid degradation of this pollutant under excitation by sunlight, highlighting the efficiency of the Fe (III)-Malonate system in the depollution of water. Transformation photoproducts are more difficult to photodegrade than the mixture itself, only the COD reduction percentages under artificial and solar irradiation are 10% and 57% respectively after 12 hours.

Keywords: Organic complex, Fe (III)-Malonate, ibuprofen, photo-Fenton, hydrogen peroxide.

I. Introduction

Our planet is largely covered with a liquid that makes its originality: water, terrestrial aquatic reserves amount to about 14 x 10^{17} m^3, of which 97.2% is contained in the seas and oceans. Fresh water represents only a small share of this total (2.8%); it is estimated that the earth contains about $39x10^{15}$ m^3 distributed in glaciers, lakes, rivers, underground reserves and the atmosphere [1]. In order to limit the arrival of these various types of refractory contaminants in the environment, effective and ecological treatment strategies have been developed. Among these strategies is the application of advanced oxidation POA processes [2].

These are oxidative treatment processes that can be grouped into four categories: Chemical oxidation processes in homogeneous phase (H_2O_2 / Fe^{2+} and H_2O_2 / O_3); Photocatalytic processes in homogeneous and / or heterogeneous phase (H_2O_2 / UV, O_3 / UV, Fe^{2+} / H_2O_2 / UV and TiO_2 / UV); Sonochemical oxidation processes, and electrochemical oxidation processes [3] . These technologies are all based on the production of radical entities, especially hydroxyl radicals ($OH^{\cdot}$), which are the most powerful oxidizing species that can be used in the field of water treatment and industrial effluents[4]. These techniques are complementary to the usual methods of flocculation, precipitation, adsorption on activated carbon or membrane processes. These POAs have been applied in several sectors, for the treatment of surface and underground water, for the elimination of odors and volatile organic compounds, the discoloration of water, the degradation of phytosanitary and pharmaceutical products, the treatment of swimming pool water , water disinfection, ultra pure water production, industrial wastewater treatment, landfill leach ate treatment and municipal sludge treatment, etc. [5] Most of these technologies have only been developed and applied on a laboratory scale, while others, such as O_3 / H_2O_2 coupling, have been proven on an industrial scale [6]. Among these processes, the homogeneous photocatalysis using Fe(III)-organic complexes is a promising new technique for the elimination of pollutants [11]. Direct photolysis of Fe(III)-carboxylate complexes leads to oxidation of the ligands with reduction of Fe(III) to Fe(II). They have been shown to play a very significant role in the production of reactive species such as $HO^{\cdot}$ %, O_2 % and H_2O_2 under irradiation. The main objective of this study is to test the efficiency of advanced oxidation process: (Fe^{3+}-Malonate complex / H_2O_2 / UV) for the treatment of waters polluted by a pharmaceutical product Ibuprofen“IBP“.

II- Experimental techniques :

II.1.Réactifs and solvants :

The following products were used: Ibuprofen (2- (4-isobutylphenyl) propionic acid), fluka> 99%, Fe (III) - Malonate complex 0.9 mM, Mohr salt (NH_4) 2Fe (SO_4). $6H_2O$, labosi, 99>%, Isopropanol, Prolabo 99%, Hydrochloric acid (HCl), Merck-proanalysis.

1,10-Phenantroline, Fluka ≥ 99% , Sodium acetate buffer (pH = 4.5) , Potassium dichromate ($K_2Cr_2O_7$), Prolabo> 99% , Mercury sulphate ($HgSO_4$), Biochem-chemophama 99%.

II.2. Chemical synthesis:

✓ **Complex Fe (III) –Malonate :**

The complex was prepared at our laboratory level. We followed the protocol described in reference [7].

II.3. Photocatalytic activity:

The efficient of the complex was tested by the degradation of Ibuprofen in aqueous solution. The test was carried out carried out in a cylindrical chamber. The UV lamp used is a Philips HPW 125 lamp emitting mainly monochromatic radiation at 365 nm (more than 80% of the radiant power), is placed in the vertical direction of the cylinder. A Pyrex reactor with a diameter of 2 cm is placed in the center, surrounded by a circulation of water so as to avoid heating solutions. The solution is stirred during the irradiation to ensure homogenization.

For the solar irradiations the tests were carried out in Constantine at the solar station of the LSTE laboratory, during the month of May 2018 during sunny days with a temperature between 20-40 ° C. The cylindrical Pyrex reactor, placed vertically. The intensity was measured using a Vilber VLX-3W radiometer equips probes centered on 365 nm and positioned at the same height of the sample.

II.4. Method of Analysis:

The absorption spectra of the solutions were recorded by a computerized "Heλios" Unicam spectrophotometer for the storage and processing of the spectra. The measurements were made in quartz tanks with an optical path of 1 cm. The HPLC analysis of the ibuprofen compounds studied and their degradation products was carried out on a SHIMADZU type HPLC system. In chromatographic analyzes of ibuprofen, the eluent used in volume is 40% water and 60% acetonitrile 0.1% acetic acid. The detection wavelength is set at 222 nm. This detector made it possible to study qualitatively and quantitatively the evolution of the concentration of reagents and main intermediates. The column used is of NUCLEOSIL 100-5 C18 type. The flow rate used in the column is 1 ml / min and the system is controlled by "Class VP5" software.

The chemical oxygen demand or COD is one of the main methods for determining the overall organic pollution of wastewater or natural water. The interest of the COD lies in the ease of implementation of the method, in its standardization (AFNOR T90-101).

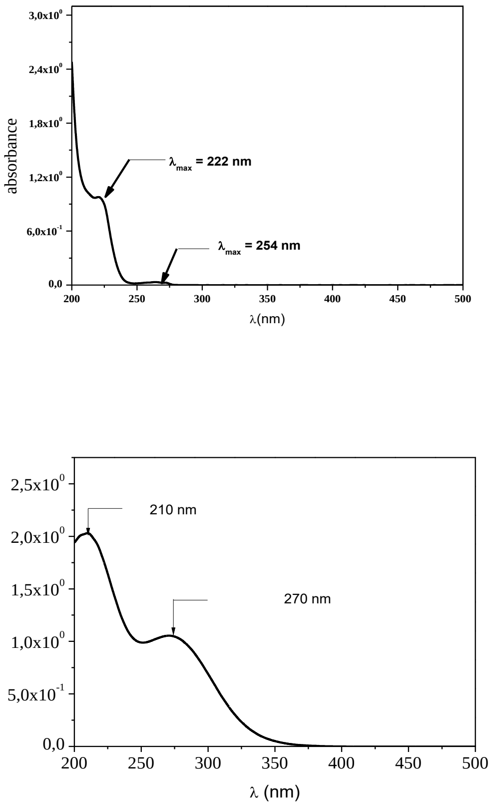
III- Results and discussion:

1) Spectral properties of “IBP” and the Fe (III) -Malonate complex:

(2- (4-isobutylphenyl) propanoic acid) named ibuprofen (IBP) is a nonsteroidal anti-inflammatory, antipyretic and analgesic steroid (NSAID) which is widely used for the treatment of inflammatory disorders such as rheumatoid arthritis as well as to relieve pain. Its chemical formula is $C_{13}H_{18}O_2$ [8].

The UV-Visible absorption spectrum of a solution containing ibuprofen 10^{-5} mol.L^{-1}, at natural pH (Figure 1a) has a band whose maximum is located at 222 nm and a second band of less intensity of which the max is located at 254 nm.

a)



b)

Figure 1: **a)** UV-Visible spectrum of a solution of IBP [IBP] = 5.10^{-5} mol.L^{-1} pH = 4.5, T = 20 ° C

b) UV-Visible spectrum of the Fe (III) -Mal [Fe (III) Mal] complex = 3.10^{-4} mol.L^{-1}, pH 2.8 and T = 15 ° C.

The UV-Visible absorption spectrum of the complex Fe (III) -Mal 3.10^{-4} mol.L^{-1} at free pH (2.8) (Figure 1b) showed that the complex absorbs strongly at 270 nm and at 210 nm whereas beyond 350 nm, the absorbance is low.

To determine the molar extinction coefficient, we chose the specific wavelength λ = 270 nm corresponding to the irradiation wavelength.

Table 1: Molar extinction coefficient of the Fe (III) - Malonate complex at 270 nm wavelengths.

λ_{max} (nm)	**R^2**	**ε expérimentale (L.cm^{-1}.mol^{-1})**	**ε théorique (L.cm^{-1}.mol^{-1})**
270	0.97	11783	11772

2) IBP Degradation in different systems at 365 nm:

We followed the evolution of the mixture under monochromatic irradiation at 365 nm. This wavelength is present in the solar spectrum and energetic enough to cause the redox reaction leading to the degradation of the pollutant.

To demonstrate the efficiency of the photo catalytic process, we verified the contribution of direct photolysis as well as photocatalys is in the process of degradation of the pollutant studied under our experimental conditions (pH = 2.8, room temperature) in the presence and the absence of hydrogen peroxide. For this, an IBP solution (5.10^{-5} mol. L^{-1}) was irradiated under the same conditions.

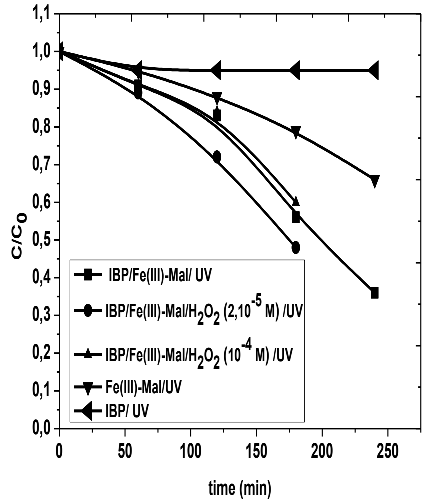


Figure 2. : Kinetics of disappearance of IBP during irradiation of the IBP-Fe (III) Mal mixture at different conditions (5.10^{-5} mol. L^{-1}, 3.10^{-4} mol. L^{-1}) at 365 nm ,pH (2.8), T = 25°C.

As seen in (Figure.2), the photo transformation of the compound by direct excitation at 365 nm is almost zero during the study period. The photochemical behavior of the IBP-Fe(III)-Malonate mixture, therefore only involves the activity of the Fe (III)-Malonate complex under light irradiation at 365 nm , during irradiation a decrease in absorbance across the spectrum is observed showing degradation of the substrate. The presence of an isobestic point at 335 nm (Figure S1) is in favor of a transformation taking place between the constituents of the IBP-Fe (III) Malonate mixture. Moreover, it should be noted that beyond 120 min of irradiation, we note the appearance of a new band located at 256nm (Figure S2).

The effect of hydrogen peroxide on IBP degradation was studied. To optimize this process which has been described as the Like-Fenton process , we compare the kinetics of disappearance of IBP during the addition of hydrogen peroxide in the presence of the Fe (III) Mal complex. The results showed when increasing the concentration of hydrogen peroxide to 10^{-4} mol. L^{-1} an appreciable acceleration of the degradation kinetics of IBP (Figure 2) is then obtained.

- **Formation of Fe (II):**

The formation of Fe (II) was also monitored.

For the IBP/Fe (III) the kinetic showed growth during the analysis interval to reach after 250 min a value equal to 10^{-4} mol. L^{-1}. This time is in perfect correlation with the maximum disappearance of IBP where we observed that the reaction is not yet complete.

In the other hand the Fe (II) formed during the photolysis of the complex show that the kinetics of formation of this element are distinguished by the presence of an induction phase where a low concentration was observed. However, for longer durations (5 hours), the kinetics increase and reach a maximum value (1.6 × 10^{-4} M) (Figure 3). The rapid formation of Fe (II) observed in the second phase is attributed to the $Fe(OH)^{2+}$ species, which becomes dominant when the ligand malonate decreases. In a second step, we verified the second element involved in the Fenton process described by the authors in the photolysis of an organic Fe (III) complex: it is hydrogen peroxide.

After adding H_2O_2 the kinetic is identical to that found previously with a value which is all the more important as the concentration of hydrogen peroxide is high Figure 4. This can be explained by the same phenomenon mentioned below.

$$Fe^{3+} + H_2O_2 \leftrightarrow Fe^{2+} + {\cdot}OH + OH^-$$

It can be explained by the existence of a reaction between H_2O_2 and Fe (III) (like Fenton) which would come from the Malonate Complex / Free Fe (III) complex equilibrium, described by certain authors Dong Xue Xiao, Yaoguang Guo, Xiaoyi Lou, Changling Fang, Zhaohui Wang, Jianshe Liu [9,10,11].(Figure 4)

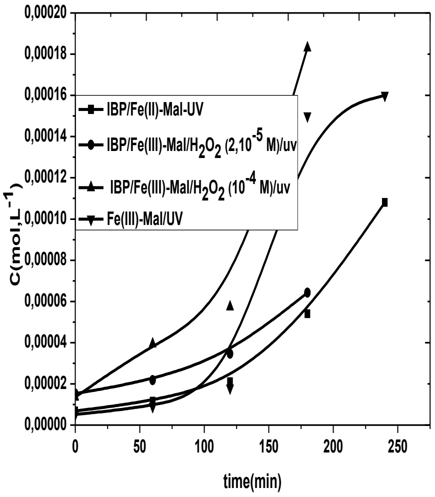


Figure 3: Formation of Fe (II) in the mixture IBP-Fe (III) Mal-H_2O_2 ([IBP] = 5.10^{-5} mol.L^{-1}, [Fe(III)-Mal] = 3.10^{-4} mol.L^{-1}, [H_2O_2] = 2.10^{-5}-10^{-4} mol.L^{-1}).

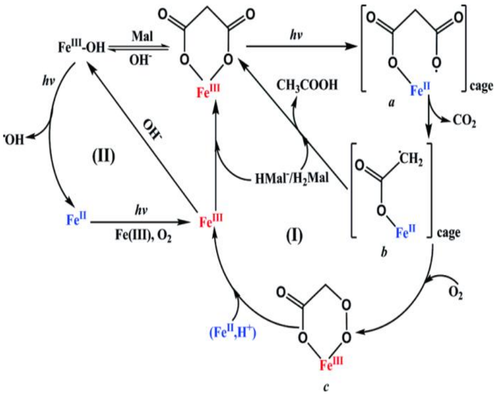


Figure4 : Mechanism of photolysis of the Fe (III) - MAO complex [10].

• Highlighting the contribution of HO$^{\cdot}$

In order to better understand the role of HO$^{\cdot}$ radicals and approves of the presence of other radicals responsible for the IBP degradation process, isopropanol is used as a scavenger of hydroxyl radicals. For this we undertook the same photochemical reaction by introducing 1% of isopropanol to the IBP-complex mixture (5.10^{-5} mol. L^{-1}, 0.3 mM, pH = 2.8).

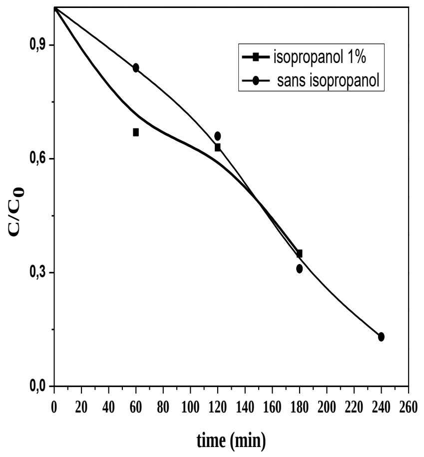


Figure 5. Disappearance of IBP upon irradiation at 365 nm of the IBP-Fe (III) Malonate system using isopropanol (1%) [IBP] = 5.10^{-5}mol.L^{-1} , [Fe(III)-Mal]= 3.10^{-4} mol.L^{-1} , pH = 2.8 , T = 25°C.

Contrary to expected, the presence of iso-propanol at low concentrations (1%) has no influence on the rate of degradation (Figure 5). It can be said from these results that the photo degradation reaction of IBP induced by the Fe (III) -Malonate complex is not linked to hydroxyl radicals. The intervention of other degradation processes may explain this result. Recent work on the photolysis of the Fe (III)-Malonate complex has revealed the presence of a $CH_2COOH°$ radical [11, 12] obtained according to the reaction:

3) Effect of pH on the IBP degradation :

The pH influences the speciation of the complex, as we mentioned earlier. To demonstrate the effect of this parameter in the photochemical process, we therefore mentioned earlier. To demonstrate the effect of this parameter in the photochemical process, we therefore undertook a study to see if a modification occurred in the course of the photochemical reaction. The IBP- IBP/Fe (III)-Malonate/H_2O_2 mixture (5.10^{-5} mol. L^{-1}, 3.10^{-4} mol. L^{-1}, pH 4.7 and 2.8) were irradiated at 365 nm.

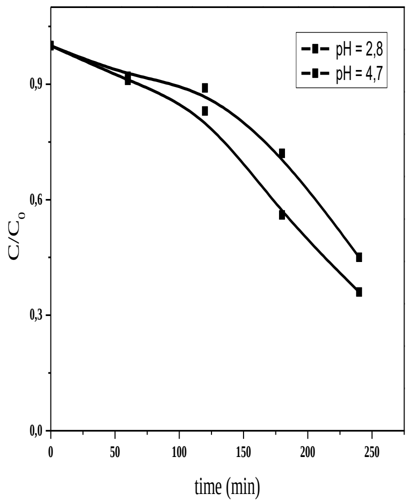


Figure6 : Kinetics of disappearance of IBP during irradiation of the IBP-Fe (III) Malonate mixture (5.10^{-5} mol. L^{-1}, 3.10^{-4} mol. L^{-1}) at 365 nm at different pH (2.8 and 4.7) , T=25°C.

By examining the substrate disappearance , the kinetics as a function of time illustrated in Figure 6 let see that the free pH have a significant effect on the degradation of IBP. In fact, at pH 2.8, 70% degradation is obtained after 250 min of irradiation, while it is reduced to 56% for pH = 4.7 for the same irradiation time. The speciation of the complex would be at the origin of this difference.

Several studies have determined the formation constants of the different forms of Fe (III) -Malonate complex. The training constants are shown in the following table.

Table 2. Formation of the different forms of the Fe (III) -Malonate complex in solution at T = 25 ° C at an ionic strength equal to 1 [13].

The shape of the complex	**pH**	**Complex formation constant (K)**
$Fe(Mal)^+$	**pH < 2**	**3,16. 10^{7}**
$Fe(Mal)_2^-$	**2 < pH < 3,5**	**1,09 10^{13}**
$Fe(Mal)_3^{3-}$	**4 < pH < 5**	**3,98 10^{16}**

In our case we can see that the most dominant form is Fe (III) -$(MaL)^-_2$, a known species more active than the other forms of the complex, is the source of this improvement.

4) Environmental significance:

- IBP Degradation in system Fe (III) Malonate-H_2O_2 under solar irradiation :

The comparison of the degradation kinetics of IBP in the presence of the Fe (III) Malonate complex and the hydrogen peroxide under natural and artificial irradiation shows that the abatement rate of IBP under natural irradiation (81%) is two greater than that obtained at laboratory level (41%) (Figure7).

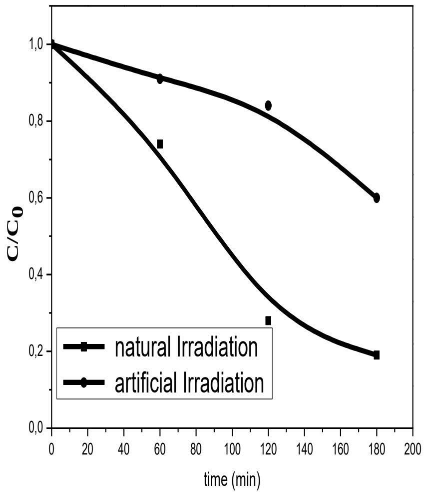


Figure 7: Evolution of disappearance of IBP in the IBP-Fe (III)-Malonate-H_2O_2 mixture ([IBP] = 5.10^{-5}mol.L^{-1}, [Fe (III)-Malonate] = 3.10^{-4} mol.L^{-1}, [H_2O_2] = 2.10^{-5} mol.L^{-1}) under natural and artificial irradiation at pH = 2.8, T= 25°C.

• Formation of Fe (II) :

Figure 8 shows the variation of the amount

of ferrous iron as a function of time during the degradation of IBP by the Fe (III) system Mal under natural and artificial irradiation. We found additional production of Fe (II) in sunlight compared to artificial light.

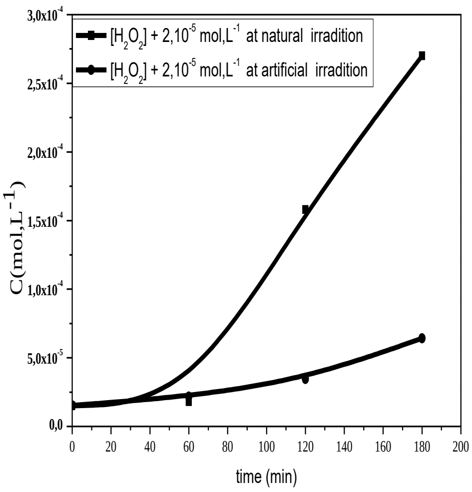


Figure8: Formation of Fe (II) in the mixture IBP-Fe (III)-Mal-H_2O_2

([IBP] = 5.10^{-5} mol.L^{-1}, [Fe (III)-Malonate] = 3.10^{-4} mol.L^{-1}, [H_2O_2] = 2.10^{-5} mol.L^{-1}) during natural and artificial irradiation at pH = 2.8, T = 25°C.

5) Mineralization

Mineralization means that the pollutant has completely transformed into mineral carbon. We followed the mineralization of IBP through the chemical oxygen demand (COD) of the mixture IBP-Fe (III) Malonate (5.10^{-5} mol.L^{-1}, 3.10^{-4} mol.L^{-1}) in solar and artificial irradiation time for 12 hours.

We chose to work at free pH which is acidic because the process is faster in this case. It is important to note that the chemical oxygen demand decreases in a slower manner irrespective of the nature of the irradiation Figure 9. The percentage of reduction of the COD under artificial and solar irradiation are 10% and 57% respectively after 12 hours. This therefore implies the need for a longer time for completion of the total mineralization.

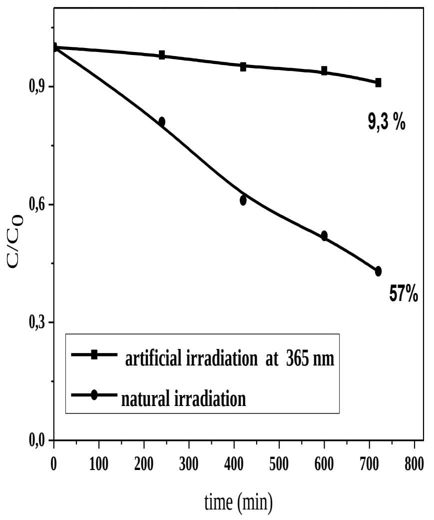


Figure 9: Evolution of the COD during the solar and artificial irradiation of the mixture ([IBP] = 5.10^{-5} mol.L^{-1}, [Fe (III) Malonate] = 3.10^{-4} mol.L^{-1}, pH = 2.8 and T = 46 ° C).

It turns out that the photochemical process under natural irradiation is much more effective than in artificial irradiation. This is related to the solar spectrum containing more energy irradiations.

IV- Conclusion

In the present work, the degradation of Ibuprofen active substance induced by the organic complex Fe (III)-Malonate with the Like-Fenton process has been studied under varieties of conditions. The obtained results showed the effectiveness of this process and the mineralization of the pollutant in natural and artificial light makes it possible and improved that this method, compatible with the environment, appears effective in the treatment of wastewater and in general in the process of water treatment .

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