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Microbiological and Physicochemical Treatments Applied to Metallurgic Industry Aiming Water Reuse

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ABSTRACT

A study was conducted on the reuse of the water in a system composed of a sewage treatment plant (STP) using prolonged aeration with activated sludge and a compact water treatment plant (CWTP) in a metallurgic industry. The processes for obtaining the water for reuse were microbiological and physicochemical. The domestic sewage was then pumped to the STP, where biological flocks were formed and clarified water was obtained. The efficiency of the microbiological process in the STP was evaluated for removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and sedimentary solids (SS). The efficiency of physicochemical processes for clarifying the water and disinfection was evaluated through analysis of pH, turbidity, color, aerobic heterotrophic bacterial count, free chlorine, hardness, alkalinity, chlorides, sulfates and dissolved total solids (DTS). In the reuse of the water, acute toxicity for the microcrustaceans Daphnia similis was also evaluated.

Key words: Water, reuse, sewage, microorganisms, disinfection

INTRODUCTION

Domestic sewage contains, on the average, 99.9% water and only 0.1% solids, with approximately 75% of these composed of the organic matter from the decomposition process. Sewage treatment plants use biological, physical and chemical processes to remove suspended and dissolved solids present in the sewage (Nuvolari et al., 2003). The activated sludge process is widely utilized for the treatment of domestic and industrial effluents. The steps involved in the biological stage of an activated sludge system are: aeration tank, sedimentation basin and sludge from recirculation (Sperling, 2002). For the success of the activated sludge process, it is necessary to maintain a mixed culture of microorganisms for the elimination of organic matter (OM), and nutrients (nitrogen and phosphorous). The heterotrophic bacteria (HB) then consume OM and form the flocks; the autotrophic bacteria eliminate the nitrogen and store the phosphorous (Trumper, 2004).

The water to be treated can contain suspended and colloidal particles. To remove these, coagulants such as aluminum sulfate, ferrous sulfate, ferric sulfate, ferric chloride, ferrous sulfate chlorinated and sodium aluminate/ aluminum sulfate are used. This stabilizes the system due to the formation of bigger clots (Vianna, 1997). The main objective of the disinfection process is to minimize the number of pathogenic microorganisms. Other processes,

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such as coagulation, flocculation, sedimentation and filtration can also reduce the microorganisms in the water. The main disinfectants used in the water treatment are chlorine, hypochlorite, chlorine dioxide, ozone, ultraviolet, and others (Haas et al., 1999).

The action of disinfectants involves three mechanisms: destruction of or damage to the structural organization of the cell; interference in energy level of metabolism; or interference in biosynthesis, growth, or the proper combination of several mechanisms such as protein synthesis, inhibition of coenzymes and enzymes. In the water treatment, the two types of predominant mechanisms of desinfection are oxidation, with later rupture of the cellular wall, and diffusion in the interior of cells, with consequent interference in cellular activities (Daniel et al., 2001).

Filtration results in the removal of particles in suspension, decrease in bacteriological load, and alterations in some chemical components. The process of filtration is based on four actions: mechanical filtration, sedimentation-adsorption; electrical effects, and biological changes (Macedo, 2000).

Adsorption of a substance involves accumulation at the interface between two phases, for example, liquid and solid. Adsorbents of interest in water treatment include activated carbon, adsorbent resins, and activated alumina, among other solids. Activated carbon can be used to adsorb specific organic molecules that cause taste and odor, mutagenicity and toxicity (Vernon and Summers, 1999).

Some microorganisms, such as *Giardia lamblia* and *Cryptosporidium parvum*, are highly resistant to disinfection, so studies have been done with fast filtration, slow filtration of sand, and filtration with membrane. The processes used most often, however, are coagulation and fast filtration, including stages of flocculation and sedimentation (Cleasby and Logsoon, 1999).

The reuse of the water can be defined as follows: After the water for a determined objective has been utilized, it can be reused after receiving appropriate treatment. The main industrial applications of treated domestic effluents are: reuse for water cooling systems, reuse for systems of steam production, reuse in industrial processes, washing of tanks and parts, washing of chimney gases - atmospheric depollution (Vitoratto and Silva, 2004).

In countries like Israel and the United States, the industrial and sewage effluents are injected back into the soil through double operation wells after being treated to refill the aquifers. Due to the abundance of water resources, Brazil has not yet adopted this practice, although it is necessary to change this mentality and consider water as a limited resource (Hespanhol, 2003).

Due to the imposition of ISO 14.000 Certifications in factories, or due to a more rigorous control by the environmental organs of the quality of water being dumped into rivers, the fact is that today, companies are concerned about the type of water that they are discarding. The evolution of water quality achieved in effluent treatment plants is generating greater awareness about the waste of discarding water after it has been treated. With this, companies began to discover alternative uses for water treated in their own industrial systems. Thus, we have entered the of “Time of Intelligent Water Use”, although it should be noted that only 1% of all water consumed in Brazil is currently reutilized (Fornari, 2005).

The objective of this study was to evaluate the reuse of the water in a metallurgic industry’s domestic sewage treatment plant composed of microbiological treatment, using activated sludge system with prolonged aeration, and physicochemical treatment using disinfection, coagulation, sedimentation and filtration.

MATERIALS AND METHODS

Raw sewage:

Raw sewage originates from bathrooms, kitchens, floor washing, and showers in a metallurgic industry.

Sewage treatment plant (STP)

A sewage treatment plant using prolonged aeration and activated sludge processes. The plant consists of an entrance compartment, an aeration tank, and a sedimentation basin.

Compact water treatment plant (CWTP):

Conventional Compact water treatment plant with entrance compartment, a mechanical flocculation chamber, sedimentation basin with decantation modules, and a filter with activated carbon, sand layers and gravel.

Other Equipment

Digimed pHmeter, Hach turbidimeter, Orion oximeter, Hach spectrophotometer, Quimis bacteriological incubator, Polilab Jar-Test, Hach thermoreactor, Tecnal BOD incubator, thermometer, Mettler analytical balance, Quimis vacuum pump.

Reagents and Materials

Ferric chloride solution, sodium carbonate solution, sodium hypochlorite solution, Hach reagents for analyzing residual free chlorine, COD and sulfates, kit for total aerobic heterotrophic bacterial (THB) count - Merck Microbiology Culti Dip Combi, filter paper, microcrustaceans *Daphnia similis*, EDTA solution, metil orange solution, hardness drain plug solution, phenolphthalein solution, black eriochrome T solution, silver nitrate solution, potassium chromate solution.

Method

The raw sewage was subjected to primary treatment composed of grating and sand compartment, and after this, was deposited in a raw sewage tank, and from this tank, was pumped into the STP for microbiological treatment by prolonged aeration and activated sludge.

With the formation of biological flocks, the sewage went to the clarifiers, resulting in clarified water and sedimented sludge. The sludge returned to the aeration tank or was removed from the system to the biodigestor and the drying beds. The clarified water receives continuous sodium hypochlorite solution (prechlorination) and then goes to the equalizer tank as according to the Fig. 1.

The water of the equalizer tank of the STP (raw water of the CWTP) was pumped to the CWTP, receiving ferric chloride solution and sodium carbonate solution. The flocculated water in continuous flow arrived into the sedimentation basin and filter. After the filter, the water received sodium hypochlorite solution as a second step in disinfection; then it was deposited in a reservoir for the reuse of water. The reuse of the water for industrial use (not potable) was pumped for use in the factory in places like cooling towers, heat exchange, and as water for moisturizers.

To evaluatesystem performance, samples were examined in a raw sewage entrance in the STP, at a STP water exit following prechlorination (equalizer tank of STP), at a CWTP water exit after the second chlorination, and in the reservoir of water intended for reuse. To verify acute toxicity for *Daphnia similis* microcrustaceans, water samples were collected from the reservoir.

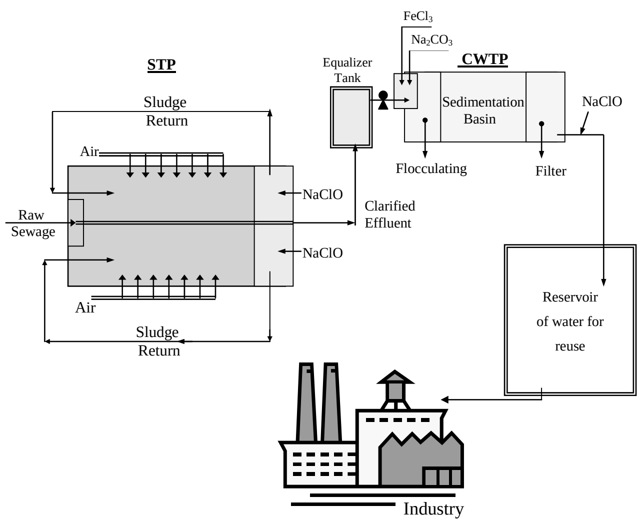

Figure 1 - Diagram of microbiological and physicochemical processes to obtain the reuse of the water

With the objective of evaluating the efficiency of microbiological processes of the STP, the parameters pH, SS, COD and $BOD_{5,20}$ of raw sewage and of STP exit water were analyzed.

In the evaluation of clarifying water and disinfection (first and second chlorination) process of the CWTP, the parameters analyzed included pH, turbidity, apparent color, residual free chlorine, alkalinity, hardness, chlorides, sulfates, DTS and acute toxicity of *Daphnia similis*. Three analyses were made for each parameter, and an arithmetic mean was calculated. All the analyses complied with the Standard Methods for the Examination of water and wastewater (Clesceri et al, 1998).

For the counting of the THB (UFC/mL), the Cult Dip Combi TTC Agar – Microbiology Merck tecnique was used for the formation of colonies. For the determination of $BOD_{5,20}$ the Norm CETESB L5.120 (1991 - a), BOD – Method of Dilution and Incubation 20ºC, 5 days was used. For the assay of the acute toxicity for microcrustaceans *Daphnia similis* the Norm CETESB L5. 018 (1991 - b) – Test of Acute Toxicity with *Daphnia similis* was used. To obtain the percent reduction in the parameters, the expression was:

$$\% \text{ reduction} = \frac{(I - F) \times 100\ \%}{I}$$

where

I = Value of parameter before treatment process

F = Value of parameter after treatment process

RESULTS AND DISCUSSION

Table 1 shows the results of the raw sewage of the STP exit water and, later, of the microbiological treatment with prolonged aeration and activated sludge. The raw sewage presented the characteristics of pH 6.3 to 7.2, SS 0.5 to 16.0 ml/l, COD 326 to 1131 mg/l O_2 and $BOD_{5,20}$ 100 to 608 mg/l O_2. The STP exit water in the equalization tanks after prechlorination presented these values in the following parameters: pH 6.7 to 7.8, SSD 0.0 to 0.8 mL/l, COD 5 to 65 mg/L O_2 and $BOD_{5,20}$ 1 to 17 mg/l O_2. The average percentage of organic load removal that occurred in the STP by the action of microorganisms was of SS 91.0% (standard deviation, σ = 9.3), COD 96.7% (σ = 2.2) and $BOD_{5,20}$ 97.5 % (σ = 1.6). The samples of STP exit water collected after chlorination with sodium hypochlorite solution (equalization tank - raw water of CWTP) presented physicochemical parameters with the following values: pH 6.7 to 7.8, turbidity 2.3 to 13.5 NTU, apparent color 50 to 237 PtCo, residual free chlorine 0.05 to 2.02 mg/l Cl_2, total alkalinity 55 to 178 mg/l $CaCO_3$, hardness 79 to 116 mg/l $CaCO_3$, chlorides 139 to 182 mg/l Cl^-, sulfates 88 to 122 mg/l SO_4^{2-} and DTS 927 to 1224 mg/l. After the physicochemical process in the CWTP of prechlorination, coagulation, flocculation, filtration, adsorption and second chlorination, as shown Fig. 1, the water samples collected presented parameters with the following values**:** pH 7.5 to 8.0, turbidity 0.33 to 1.20 NTU, apparent color 10 to 30 PtCo, residual free chlorine 0.08 to 1.78 mg/l Cl_2, total alkalinity 67 to 198 mg/l $CaCO_3$, hardness 76 to 108 mg/l $CaCO_3$, chlorides 160 to 205 mg/l Cl^-, sulfates 90 to 124 mg/l SO_4^{2-} and DTS 956 to 1248 mg/l. In the process used in the CWTP, it was observed a decreasing of turbidity and apparent color of an average of 85.7% (σ = 5.8) and 78.2% (σ = 6.6), respectively, were observed. The elevation of pH and alkalinity of this water was a function of the addition of the sodium carbonate solution to adjust the pH of coagulation. The increase in the values of the chloride was due to the dosage of the ferric chloride coagulant and the sodium hypochlorite solution.

The alkalinity and pH of this water were kept at these levels with the objective of avoiding corrosion in the industrial water reutilization system. The turbidity values of most of the samples remained between 0.50 and 0.65 NTU, what contributed to assuring the removal of enteroviruses, cysts of *Giardia spp* and oocysts of *Cryptosporidium sp*, since the process of chlorination was inefficient in eliminating them.

The reuse of the water in the reservoir after stabilization presented low free residual chlorine. The likely reasons were: chlorine evaporation, chlorine consumption in the oxidation of the remaining organic matter and elimination of microorganisms. The reservoir has a residence time of 36 hours.

For the acute toxicity tests, samples were collected from the reuseable water in the reservoir, and tested in the Norm CETESB L5.018 (1991–b). The water presented physicochemical qualities within the limits of table 3, and the results of three sample tests were of null toxicity.

Table 1 - Evaluation of the efficiency of the microbiologic process with prolonged aeration and activated sludge in the removal of sedimentary solids (SS), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD).
x = average value; **σ** = standard deviation

Number of Samples	Raw Sewage				STP Exit Water				% Reduction		
	pH	SS (ml/l)	COD (mg/l)	$BOD_{5,20}$ (mg/l)	pH	SS (ml/l)	COD (mg/l)	$BOD_{5,20}$ (mg/l)	SS (ml/l)	COD (mg/l)	$BOD_{5,20}$ (mg/l)
A 1	6.9	3.1	852	354	7.5	0.1	44	16	96.8	94.8	95.5
A 2	6.8	2.0	778	143	7.1	0.1	5	1	95.0	99.3	99.3
A 3	7.2	1.4	870	308	7.2	0.1	30	7	92.9	96.5	97.7
A 4	6.5	3.5	928	283	7.0	0.8	58	10	77.1	93.7	96.5
A 5	6.8	3.0	920	317	7.4	0.1	55	13	96.7	94.0	95.9
A 6	7.0	2.0	890	502	7.6	0.1	26	15	95.0	97.0	97.0
A 7	7.0	0.5	668	193	7.0	0.0	35	4	100.0	94.8	97.9
A 8	7.0	16.0	1131	482	7.1	0.2	47	17	98.8	95.8	96.5
A 9	6.6	1.0	840	105	7.3	0.1	25	5	90.0	97.0	95.2
A 10	6.3	1.0	957	608	7.6	0.2	5	1	80.0	99.5	99.8
A 11	6.9	1.0	742	170	7.1	0.1	19	2	90.0	97.4	98.8
A 12	6.5	2.0	841	346	7.2	0.1	48	13	95.0	94.2	96.2
A 13	6.5	1.5	868	333	7.2	0.1	5	2	93.3	99.4	99.4
A 14	6.7	0.5	624	100	7.3	0.2	10	1	60.0	98.4	99.0
A 15	6.6	15.0	884	250	7.8	0.4	65	11	97.3	92.6	95.6
A 16	6.4	10.0	992	372	7.7	0.4	5	3	96.0	99.5	99.2
A 17	6.7	0.5	690	346	6.7	0.1	5	2	80.0	99.3	99.4
A 18	6.7	1.0	503	265	7.0	0.1	5	2	90.0	99.0	99.3
A 19	6.6	1.5	357	115	7.1	0.0	10	3	100.0	97.2	97.4
A 20	6.4	1.5	326	148	7.4	0.1	18	8	93.3	94.5	94.6
A 21	6.6	1.5	810	260	7.2	0.1	34	8	93.3	95.8	96.9
x	6.7	3.3	784	286	7.3	0.2	26	7	91.0	96.7	97.5
σ	0.2	4.4	195	133	0.3	0.2	20	5	9.3	2.2	1.6

Table 2 - Bacteria decrease (%) during the disinfection process. Comparison between the exit water of the sewage treatment plant and the (Reservoir).

Number of Samples	STP Exit Water before chlorination (bact/mL)	Water (Reservoir) after chlorination (bact/mL)	Bacteria decrease (%) in the disinfection process
01	10^7	10^3	99.99
02	10^7	10^3	99.99
03	10^6	$< 10^3$	> 99.90
04	10^8	10^3	99.99
05	10^7	$< 10^3$	> 99.99
06	10^7	$< 10^3$	> 99.99
07	10^7	$< 10^3$	> 99.99
08	10^7	10^4	99.90
09	10^6	$< 10^3$	> 99.90
10	10^7	10^3	99.99
11	10^8	10^3	99.99
12	10^7	$< 10^3$	> 99.99
13	10^7	$< 10^3$	> 99.99
14	10^7	$< 10^3$	> 99.99
15	10^8	$< 10^3$	> 99.99
16	10^7	10^4	99.90
17	10^6	$< 10^3$	> 99.90
18	10^7	10^3	99.99
19	10^7	$< 10^3$	> 99.99
20	10^8	10^4	99.99
21	10^7	$< 10^3$	> 99.99

Table 3 - Quality of the water in the reservoir (water for reuse).

Number of Sample	pH	Turbidity (NTU)	Apparent Color (PtCo)	Residual Free Chlorine (mg/l)	Total Alkalinity (mg/l)	Hardness (mg/l)	Chlorides (mg/l)	Sulfates (mg/l)	DTS (mg/l)
AR 1	7.8	0.59	14	0.03	153	92	181	92	1015
AR 2	7.7	0.48	20	0.02	87	90	185	94	1255
AR 3	7.8	0.50	19	0.03	142	80	185	86	1097
AR 4	8.0	0.51	17	0.03	120	74	206	90	1155
AR 5	7.8	0.62	21	0.04	98	94	178	94	1177
AR 6	7.9	0.64	20	0.03	109	78	142	108	1174
AR 7	7.9	0.44	20	0.04	131	80	149	100	1098
AR 8	8.0	0.79	19	0.03	109	78	178	92	1130
AR 9	7.8	0.70	26	0.06	186	84	171	110	1111
AR 10	7.7	0.61	17	0.04	131	78	192	112	1212
AR 11	7.8	0.70	23	0.04	153	88	178	98	1189
AR 12	7.6	0.44	18	0.04	87	80	196	92	1211
AR 13	8.2	0.61	23	0.03	130	82	162	98	1244
AR 14	8.3	0.62	20	0.03	97	80	154	98	1099
AR 15	7.6	0.55	10	0.03	111	78	189	110	1165
AR 16	7.7	1.10	26	0.02	110	80	168	108	1183
AR 17	8.0	0.57	23	0.05	212	74	196	98	1170
AR 18	7.8	0.55	17	0.05	200	80	175	104	1038
AR 19	7.5	0.51	13	0.03	161	78	182	102	1100
AR 20	7.8	0.87	15	0.05	204	72	196	94	1133
AR 21	7.8	0.49	13	0.05	193	78	189	110	1111
x	7.8	0.61	19	0.04	139	81	179	100	1146
σ	0.2	0.15	4	0.01	39	6	16	8	60

x = average value; **σ** = standard deviation

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RESUMO

Estudou-se o reuso de água de um sistema composto por estação de tratamento de esgoto (ETE) com aeração prolongada e lodo ativado, e em uma estação compacta de tratamento de água (ECTA) de uma indústria metalúrgica.
Os processos para obtenção da água de reuso foram: microbiológico e físico-químico. O esgoto doméstico foi bombeado para a ETE, onde houve formação de flocos biológicos e água clarificada. Avaliou-se a eficiência do processo microbiológico da ETE mediante a remoção de demanda bioquímica de oxigênio (DBO), demanda química de oxigênio (DQO) e sólidos sedimentáveis (SS). A eficiência do processo físico-químico de clarificação e desinfecção foi avaliada mediante análises de pH, turbidez, cor, contagem de bactérias heterotróficas aeróbias, cloro livre, dureza, alcalinidade, cloretos, sulfatos, sólidos totais dissolvidos (STD). Na água de reuso além desses parâmetros avaliou-se a toxicidade aguda ao microcrustáceo *Daphnia similis*.

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