3. OVERVIEW OF RADIATION TECHNOLOGY FOR ENVIRONMENTAL REMEDIATION IN BRAZIL

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Abstract

The necessity to decrease the environmental contamination caused by toxic flue gases, liquid and solid effluent delivered by industries, have resulted in search of new treatment technologies. The ionizing radiation is efficient on destroying organic compounds delivered in industrial effluents, independent on the physical-chemical characteristics and origin. Experiments had been performed at laboratory and at pilot plant scale using Electron Beam Facility with a 1.5 MeV, Dynamitron from Radiation Dynamics Inc. with actual effluents from different industries such as chemical, petroleum, wastewater treatment plant, and drinking water. The efficiency evaluation for each case was accomplished by the physicochemical, chemical and toxicity analysis, in addition, the economic analysis of the process. Some studies were done combining technologies with the objective of improving the efficiency for high-contaminated effluents and decreasing the required absorbed doses for future implementation to large-scale design. Technical and economic feasibility study for implementation of a mobile unit for treatment of industrial effluents with electron beam was carried out, and nowadays, the main focus of the group is the construction of a mobile electron beam wastewater treatment plant for technology demonstration *in situ*.

3.1.OBJECTIVE OF THE RESEARCH

The main objective is to demonstrate the efficiency of ionizing radiation treatment of water and actual wastewater from distinct origin and with different physical chemical characteristics and organic compounds concentration, through the data obtained by the research group from Energy and Nuclear Research Institute, IPEN-CNEN/SP, in the period of 1992 up to 2014.

3.2.INTRODUCTION

Radiation Technology Centre at IPEN-CNEN/SP started in 1992 the development of an alternative technology for wastewater and industrial effluent treatment, mainly for the degradation of pollutants, using the radiation from a high-energy electron beam accelerator (EB). This technology has been extensively studied by many research centers in the world but the use of this technology into environmental area has been moved slowly because industry and government is always conservative in adoption of new process, especially when they cannot observe the efficiency and cost effectiveness of a treatment in a full scale facility. The reactive species formed by the water irradiation are the reducing radicals, solvated electron (e-aq) and H. atoms and the oxidizing radical hydroxyl OH. These reactive species will react with organic compounds in the water inducing their decomposition. The use of ionizing radiation has great ecological and technological advantages, especially when compared to physical-chemical and biological methods. It degrades organic compounds, generating substances that are easily biodegraded without the necessity of adding chemical compounds [3.1–3.7].

A lot of experiments were done at laboratory scale and based on these data, a pilot plant for large-scale experiments was set up in the IPEN-CNEN/SP EB facility[8], in order to study the removal and degradation efficiency of toxic and refractory pollutants (organic compounds mainly from industrial origins) and the disinfecting of pathogenic microorganisms in wastewater, industrial effluents and sludge. The economic feasibility study and the results of the performed tests could be used to scale up for a demonstration plant on a commercial basis.

The IPEN-CNEN/SP´s pilot plant can process a stream at a flow rate of 0.5 m^3 per hour up to 6.0 m^3 per hour with an average dose rate of 5 kGy. Two tanks with 1,200 liters capacity are used for storage and collection of the treated liquid and two pumps are used to homogenize and pump the liquid through the irradiation device, specially built for this purpose. A system allows the sample collection just after and before irradiation. The Electron Beam Accelerator is 1.5 MeV from Radiation Dynamics Inc., the beam current range from 1mA up to 25 mA and the electron beam is scanned on a 60 cm length and 4 cm width area, at a frequency of 100Hz [3.8].

The absorbed dose is measured by calorimetric system using a WCOTT Wire Current Output Temperature Transducer, which allows obtaining in real time the average absorbed doses. Two WCOTT are used, one in the influent and the other in the effluent stream and they are connected via an interface to a computer which continuously reads and records temperatures, the absorbed dose is calculated by the conversion of the temperature difference to the equivalent energy transferred to the stream. It's important to note that the irradiation device that was designed by the IPEN-CNEN/SP´s staff has innovative configurations, which reduce the dependence of electron beam voltage acceleration on the efficiency of energy transferred to the stream in order to reduce the costs of the facility including the EB machine and irradiation vault [3.9].

Radiation-initiated degradation of organics helps to transform various pollutants into less harmful substances or reduced to the levels below the permissible concentrations for wastewater reuse in urban irrigation, agriculture, and industry. Radiation processing is an eco-friendly technology and offers the following advantages: no addition of chemical compounds; no heating and easy for automation; in situ generation of the reactive species which are strong reducing and oxidizing agents for efficient decomposition of pollutants; absence of hazardous by-products (no secondary waste generation); converting no-biodegradable pollutants into biodegradable substances from industrial wastewater facilitating the treatment by conventional technology; easy to integrate with the existing systems and has economic advantages in comparison with most of the conventional technologies [3.7].

3.3.EXPERIMENTAL

Experiments had been performed at laboratory and at pilot plant scale, for each case study the following analysis were accomplished: physical, chemical, and toxicity of real wastewater before and after irradiation. In addition economic analysis of the process was performed.

3.3.1. In partnership with sanitation company SABESP

SABESP is a mixed capital company responsible for providing water and sewage service in 364 municipalities of the State of Sao Paulo, Brazil, and it is considered one of the largest water and sewage service provider companies in the world, based on the number of customers. A population of 27.7 million people is directly and indirectly supplied with water and 21.6 million people have sewage collection. In partnership with SABESP studies were performed on EB application in samples from different origin and different problems as the drinking water treatment plant and wastewater treatment plant.

3.3.1.1. Drinking Water Treatment Plant

The cyanobacteria, or blue-green algae, owe their name to the presence of photosynthetic pigments. Freshwater cyanobacteria are known to occur throughout the world. The main responsible organic composites for the taste and odor type earth and mould of surface waters used to supply throughout the world are geosmin (GEO) and 2-methylisoborneol (MIB). Geosmin (*trans*-1, 10-dimethyl-*trans*-decalol) is and 2-methylisoborneol is compounding produced by several species of cyanobacteria (blue-green algae) and is extremely difficult to degrade microbiologically. Conventional treatment processes of surface water are not effective in removing or destroying the cyanobacteria toxins. However, certain oxidation procedures as well as activated charcoal were found to be effective [3.10].

3.3.1.2. Wastewater Treatment Plant

The Suzano Wastewater Treatment Plant (WTP) has a processing capacity of 1.5m^3/s, receiving domestic and industrial wastewater from five different cities. About 30% of wastewater in this plant is from chemical, pharmaceutical, textile and dyes industries origin. Five steps of the conventional treatment of the WTP were selected for sampling: Industrial Receiver Unit influent (IRU), Coarse Bar Screens effluent (CBS), Medium Bar Screens effluent (MBS), Primary Sedimentation effluent (PS) and Final Effluent (FE). The IRU and CBS receive exclusively effluent from industrial origin. The samples were collect following the schedule: four sampling each two hours from each step (composed samples), biweekly during 8 months [3.11–3.12].

3.3.2. In partnership with Industrial Complex

The effluents were from an industrial complex composed by eight separated production units named: Intermediary Organic Products (IOP), Poly Vinyl Acetate (PVA), Resins (RES), Special Products (SP), Detergents (DET), Sulphonation (SULF), Thiodan (THIO), and Azo dyes (AZO). Each unit delivered its effluent to the small treatment plant, where they were mixed and the pH was neutralized. One effluent sample from each of eight separate industrial units (IOP, PVA, RES, SP, DET, SULF, THIO and AZO) and 5 samples from the mixed effluent (ME1 to ME5), were irradiated at IPENs Pilot Plant [3.13–3.15].

3.3.3. In partnership with PETROBRAS/CENPES

PETROBRAS is a publicly traded corporation, the majority stockholder of which is the Government of Brazil, performed as an integrated energy company in the following sectors: exploration and production, refining, marketing, transportation, petrochemicals, oil product distribution, natural gas, electricity, chemical gas, and biofuels. As leader in the Brazilian oil industry, the company has expanded its operations aiming to be among the top five integrated energy companies in the world by 2030 and has a presence in 25 countries. The studies were performed in two distinct areas that are the treatment of effluent from petroleum production and the petroleum and diesel fuel desulfurization enhancement.

3.3.3.1. Effluent from Petroleum Production

During the offshore oil production large volumes of aqueous waste with high salinity are produced. The produced water originates mainly from the oil-bearing formation but may also include seawater, which has been injected to maintain reservoir pressure. This water is normally separated from oil on the platform generating aqueous effluent with metals, sulfite, ammonium, and organic compounds. The conventional treatment used includes filtration, flotation, ionic change, and adsorption in activated charcoal, but the high salinity of this water decreases the efficiency of those treatments [3.16–3.17].

3.3.3.2. Petroleum desulfurization

Nowadays sulfuric and high-sulfuric crude oils make up a majority of the world-produced oil. The total sulfur content in these sorts of oil varies in a very wide range from 0.5 up to 10mass%. Composition of the sulfur-containing organic compounds is complicated and multifarious: more than 250 compounds are identified today. The main part of sulfur in oil is represented by such organic compounds as mercaptans RSH, sulfides RSR, disulfides RSSR and cyclic sulfides CnH_2nS. The amount of 4 $x10^7$ tons of sulfur is annually burned out together with the oil products. In translation to combustion products, it makes $8x10^7$ tons of sulfur dioxide or $1.2x10^8$ tons of sulfuric acid. Production of these products results in precipitation of acid rains and increase in the sickness rate of the inhabitants [3.18–3.20].

3.3.4. In partnership with other companies

The developments carried out with different partnerships using EB on degradation of contaminants were:

- Degradation of pesticides in soil and packaging [3.21–3.26];
- Pharmaceuticals studies: fluoxetine (Prozac®) and mixtures of pharmaceuticals for degradation and toxicity reduction [3.26–3.27];
- Reactive organic dyes and detergents and their effluents in order to improve their treatment by radiation combined process [3.27–3.28];
- Treatment of effluent from industrial automotive and refinish paints for reuse.

3.3.5. Radiation Processing

Electron Beam Facility with a 1.5 MeV, type Dynamitron from Radiation Dynamics Inc. was used. The irradiation parameters of EB accelerator were 4.0 mm sample width, scan of 112 cm (94.1%) and stream velocity of 6.72 m/min.

Effluents from industrial chemical complex were irradiated at the IPEN's Electron Beam Pilot Plant that was set up to treat wastewater and industrial effluents. The IPEN-CNEN/SP's pilot plant can process a stream at a flow rate of 0.5 m^3 per hour up to 6.0 m^3 per hour with an average dose rate of 5 kGy. Two tanks with 1,200 liters capacity are used for storage and collection of the treated liquid and two pumps are used to homogenize and pump the liquid through the irradiation device specially built for this purpose. A sample system allows the sample collection just after and before irradiation.

3.3.6. Dosimeter system

The absorbed dose was measured by calorimetric system using a temperature transducer type, WCOTT, Wire Current Output temperature transducer, - Intensil, GEAD590, that allows to obtain in real time the average absorbed doses. The sample stream had a medium flow rate of 30 L/min; the electron beam had energy 1.5 MeV and the current was varied from 1.2 mA to 10.6 mA in order to obtain the desired doses [3.4, 3.8].

3.3.7. Evaluation of the process efficiency

The irradiation treatment efficiency was evaluated by the chemical and toxicity analysis of the samples before and after irradiation. The organic compounds were analyzed by Gas chromatograph associated to mass spectrometry using Gas Chromatograph associated to Mass Spectrometer Shimadzu model GCMS-QP 5000.

3.4.RESULTS AND DISCUSSION

3.4.1. Drinking Water Treatment

The results of quantitative analyses of organic compounds GEO and MIB in the three kinds of water samples before and after gamma irradiation with 0.5 kGy, 1.0 kGy, 2.0kGy and 3.0 kGy showed a total removal of GEO and MIB with 0.5 kGy of absorbed dose and the concentrations were near 100 ngL^{-1} in case of sediment water and final water, raw water presented lower reduction. In the case of samples, which concentrations were near to 1000 ngL^{-1}, it was necessary higher doses to remove 90% of GEO and MIB. For final and sediment water it was necessary 2.0 kGy to remove 99%. It was not observed acute toxicity in the samples before neither after irradiation. The absence of acute toxicity mainly when 3kGy of absorbed dose was applied is important to verify that no toxic substances were formed after the radiation processing [3.10].

3.4.2. Effluent from Wastewater Treatment Plant

Samples from IRU and CBS are mainly of industrial origin, resulting high Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD). In the MBS point occur the reception of domestic wastewater then the organic load increase, resulting in very high Total Organic Carbon; but this organic load represents proteins, carbohydrates, oils and greases but not toxic organic pollutants. The steps that presented more toxic organic compounds were IRU and CBS and the main organic compounds found were dichloroethane, toluene, xylene, methilisobutylketon, and phenol. Samples from the IRU, CBS and MBS steps presented the highest concentrations of organic compounds then it was necessary absorbed doses from 20kGy to 50kGy to remove 90%, while samples from PS needed absorbed doses from 10kGy to 20kGy and FE needed 10 kGy doses. Although the MBS samples presented lower concentrations of organic compounds than IRU and CBS steps, the necessary absorbed dose to remove 90% of the main organic compounds was the same, it may be because the highest organic load concentration that compete to the oxidation by radiation. This can be seen by the yield of Destruction (G_d) value obtained for MBS that is lower than G_d value obtained for IRU and CBS in all studied organic compounds (Table 3.1). Phenol presented negative results on removal in the steps IRU, CBS and MBS when irradiated at doses of 10 kGy and 20 kGy, that is because it was observed an increase in its concentration when lower doses were applied. This occurrence suggest a phenol molecule formation when aromatic compounds are oxidized, because this, the G_d of phenol presented lower values than the others studied organic compounds [3.8, 3.6, 3.11, 3.18, 3.23, 3.29].

3.4.3. Effluent from Industrial Complex

The physical chemical characterization of these samples showed the complexity and differences of these effluents. The pH ranged from 1.40 (IOP) to 12.80 (AZO), Chemical Oxygen Demand (COD) was from 466 mgO_2/L (THIO) to 29,00 mgO_2/L (DET), sulphates from 70 mg/L (SP) to 22,780 (AZO), oil and greases from 21 mg/L (ME5) to 285 mg/L (DET) and the suspended solids from 58 mg/L (SULF) to 494 mg/L (DET). The most important pollutants found in these effluents were chloroform, dichloroethane, methyl isobutyl ketone, toluene, xylene, and phenol. The necessary dose to remove 90% of these contaminants was presented in Table 3.2 [3.17, 3.19, 3.25–3.26, and 3.30].

TABLE 3.1. ORGANIC COMPOUNDS CONCENTRATION IN WASTEWATER TREATMENT PLANT STEPS AND THEIR REMOVAL AFTER EB IRRADIATION

ORGANIC COMPOUNDS	IRU	CBS	MBS	PS	FE
	Concentration (mg/L)				
Methylisobutyl ketone	1.00 - 22.30 *(20)*	1.30 - 7.85 *(20)*	0.22 - 3.52 *(20)*	0.98 - 2.69 *(10)*	<dl
Dichoroethane	1.30 - 25.70 *(20)*	1.10 - 16.00 *(20)*	1.86 - 5.58 *(20)*	0.98 - 3.69 *(10)*	0.40 - 1.85 *(5)*
Toluene	0.80 - 12.00 *(50)*	1.00 - 72.00 *(50)*	0.51 - 2.57 *(20)*	0.85 - 1.60 *(10)*	0.32 - 1.97 *(5)*
Xylene	1.50 - 67.00 *(50)*	0.50 - 25.70 *(50)*	1.22 - 3.51 *(20)*	0.96 - 1.82 *(10)*	0.12 - 4.00 *(5)*
Phenol	3.20 - 7.80 *(50)*	3.20 - 16.40 *(50)*	0.96 - 2.00 *(20)*	0.86 - 1.60 *(10)*	0.50 - 0.86 *(5)*

dl = detection limit = 0.03 mg/L

Variation = 10%

() Necessary Absorbed Dose to 90% removal

3.4.4. Effluent from petroleum production

Although originated of the same process, samples from *Production Unit A* and *Production Unit B* showed very different physical-chemical characteristics, such as the higher ammonium concentration and lower sulphite concentration of the samples from *Production Unit A*, and the pH ranged from 9.28 up to 9.88 in *Production Unit A* and from 7.88 up to 8.07 in *Production Unit* B. The most important organic pollutants in both effluent samples were benzene, toluene, ethylbenzene, xylene; and all these pollutants present higher concentration in the samples from *Production Unit A* than *Production Unit B*, Phenol was found in relative low concentration but was considered due to its toxicity and because phenol is formed as first by-product of the degradation of benzene and toluene. From these results the complexity and differences of these effluents can be observed. After radiation processing, the organic

TABLE 3.2. ORGANIC COMPOUNDS CONCENTRATION IN INDUSTRIAL EFFLUENT AND THEIR REMOVAL AFTER EB IRRADIATION

Sample	Dichloroethane (mg/L)	CHLOROFORM (mg/L)	METHYL ISOBUTHYL KETON (mg/L)	Toluene (mg/L)	XYLENE (mg/L)	*Phenol* (mg/L)
			MIXED EFFLUENT			
ME1	87.93 *(20)*	0.83 *(20)*	na	6.32 *(20)*	9.31 *(15)*	2.81 *(50)*
ME2	2.65 *(20)*	0.18 *(20)*	na	1.10 *(20)*	1.52 *(20)*	3.25 *(50)*
ME3	0.23 *(20)*	<0.010	na	1.81 *(20)*	0.12 *(20)*	0.04 *(50)*
ME4	51.32 *(20)*	0.51 *(20)*	24.21 *(20)*	13.08 *(20)*	24.33 *(30)*	2.32 *(50)*
ME5	65.75 *(30)*	0.83 *(20)*	33.96 *(20)*	25.31 *(10)*	27.21 *(10)*	1.92 *(50)*
			Separated units			
SP	<0.010	<0.010	na	<0.10	<0.10	0.62 *(50)*
RES	<0.010	<0.010	na	6.22 *(50)*	<0.10	1.61 *(50)*
PVA	<0.010	<0.010	na	0.30 *(50)*	<0.10	1.91 *(50)*
DET	<0.010	<0.010	na	0.27 *(50)*	0.23 *(50)*	1.11 *(50)*
IOP	28.4 *(50)*	<0.010	na	<0.10	<0.10	0.62 *(50)*
SULF	0.15 *(50)*	<0.010	na	<0.10	<0.10	<0.10
THIO	1.85 *(30)*	<0.010	na	<0.10	<0.10	0.41 *(50)*
AZO	11.38 *(50)*	0.21 *(20)*	na	<0.10	2.14 *(20)*	<0.10

na = not analyzed

( ) = necessary dose (kGy) to 90% removal

Compounds content showed a substantial reduction, but with very high absorbed doses. For samples from *Production Unit A*, a dose of 100kGy was necessary to remove more than 90% of all organic compounds, and in the case of *Production Unit B* a dose of 20kGy was enough to remove 90% of BTEX and phenol in all samples. The exact influence of ammonium concentration is presently not clear enough, but these results would suggest a positive effect in the removal of organic compound after electron beam processing, since the *SA*2 and SA4 with higher ammonium concentration have the higher yield (G_d) for BTEX and opposite happened with SA3 (Table 3.2). The degradation yield of the substrate depends on its starting concentration, hence the process was more effective when high number of organic molecules was present, because the reaction among reactive transients produces more radicals and the process continue, but it is not a direct proportion. E.g. in the case of Benzene in samples from PUA has higher concentration than samples from PUB, about three times, but the Gd values was almost the same [3.1, 3.15, 3.16].

TABLE 3.3. ORGANIC COMPOUNDS CONCENTRATION IN PETROLEUM PRODUCTION EFFLUENT AND THEIR REMOVAL AFTER EB IRRADIATION

SAMPLE	BENZENE (mg/L)	Toluene (mg/L)	XYLENE (mg/L)	*Phenol* (mg/L)
SA1	99.30 (100)	134.49 (100)	307.00 (100)	4.24 (50)
SA2	146.80 (100)	218.22 (100)	585.06 (50)	3.27 (50)
SA3	119.79 (100)	195.36 (100)	333.44 (100)	1.47 (50)
SA4	111.71 (100)	216.93 (100)	243.24 (50)	1.39 (50)
SB1	22.46 (20)	8.53 (20)	6.61 (20)	3.73 (20)
SB2	42.17 (50)	27.12 (50)	24.40 (50)	1.92 (20)
SB3	35.30 (20)	20.83 (20)	12.65 (20)	1.65 (20)
SB4	49.05 (20)	27.33 (20)	17.70 (20)	0.98 (20)

() Necessary Absorbed Dose (kGy) to 90% removal

In another experiment the samples were mixture with 0.1, 0.2, 0.5 and 1.0 g/L of TiO_2 in powder form, Degussa P-25 catalyst, hybrid mixture of rutile (approx. 70%), and anatase form. The vials were completely filled without headspace. The obtained results of removal efficiency using different absorbed doses and Titanium Oxide concentrations are showed in the Table 3.4. It was expect that TiO_2 combined to ionizing radiation would increase the removal of the BTX, but the synergistic effect showed not linear form. The lower concentration of TiO_2 (0.1 g/L and 0.2 g/L) increased the BTX removal efficiency for 10 kGy and 20 kGy of absorbed doses, but for higher doses it didn't make any difference and in higher concentrations (1.0 g/L) the

removal efficiency decreased. When higher absorbed doses were applied the removal efficiencies of ionizing radiation alone or combined with TiO_2 were almost the same. The presence of TiO_2 also increased the discoloration of the industrial effluent, significant reductions occur when 0.1 g/L and 0.2 g/L were added, but with higher concentration the results showed similar [3.22].

TABLE 3.4. ORGANIC COMPOUNDS REMOVAL IN PETROLEUM PRODUCTION EFFLUENT AFTER EB IRRADIATION PLUS TITANIUM DIOXID

Organic compound	TiO_2 (g/L)	Removal Efficiency (%)				
		Absorbed Dose (kGy)				
		0.0	10.0	20.0	50.0	100.0
Benzene	0.0	0.00	14.29	28.57	94.76	99.52
	0.1	0.00	11.76	23.53	94.71	98.24
	0.2	0.00	11.76	52.94	96.47	98.82
	0.5	0.00	14.29	57.14	96.43	99.29
	1.0	0.00	14.29	21.43	95.71	99.29
Toluene	0.0	0.00	26.19	44.29	66.19	96.19
	0.1	0.00	27.78	33.95	59.26	95.06
	0.2	0.00	20.78	56.49	66.23	98.70
	0.5	0.00	19.08	55.73	79.39	99.77
	1.0	0.00	17.53	12.37	49.48	99.69
Xylene	0.0	0.00	12.50	27.08	63.19	93.06
	0.1	0.00	12.00	38.00	68.00	94.00
	0.2	0.00	12.33	86.30	94.52	99.59
	0.5	0.00	16.67	71.67	99.50	99.50
	1.0	0.00	13.33	66.67	99.00	99.00

3.5.FINAL CONSIDERATIONS

The electron beam processing has shown high effectiveness on removal organic compounds in complex effluents. In terms of yield *Gd* values, the process showed more effectiveness when high organic molecules number are present, because the reaction among reactive transients produces more radicals continuing the process [3.13–3.15]. As described earlier, in partnership with various industrial partners, studies were performed on EB application in samples from

different origin and different problems as the drinking water treatment plant and wastewater treatment plants [3.31-3.36].

Besides the high necessary absorbed doses, it is a promising process for future field implementation because, the high complexity of the effluent become its treatment by others technologies, very expensive and not so efficient. Ionizing radiation from EB accelerator is an alternative in the treatment of water and wastewater and for desulfurization enhancement in petroleum and diesel fuel, as it works on the basis of electricity and, according to the purpose, small machines can be built for easy handling and transport for use in different locations, and can be used in combination with other techniques. Homogeneous dose distribution in the irradiated layer has been solved with the development of appropriate irradiation system.

Another point to be considered is the water reuse, that is becoming increasingly important in large industrial centers, where water scarcity represents high operational costs for impounding and distribution, e.g. in Brazil, Sao Paulo water utility charges about 3.80 USD/m^3 for water and additionally industries paying the equivalent value for effluent disposal in water bodies, totaling to about 8.34 USD/m^3, whereas the price of recycled water is about 0.90 USD per cubic meter.

It's important to point out the following considerations about the radiation processing technology using EB accelerator to treat contaminated effluents:

- Technology can be used: the chosen process can be an alternative for treatment of industrial effluent, the rational for this conclusion is precisely in compliance with Brazilian Decree N. 8468 of 1976;
- Processing speed: compared with traditional wastewater treatment process, this technology proved to be much faster;
- Contribution to sustainability: the wastewater treatment using EB accelerator is a simple process and does not use other chemical products;
- Non-selective process: there is no way to select which product will be degraded, the technology acts uniformly;
- Cost reduction: technology does not require raw materials or other supporting product to eliminate the hazard or minimize the environmental impacts;
- Temperature: electron beam irradiation does not depend on the temperature, since the processing is carried out at room temperature;
- By-product: no sludge production, when compared with traditional processes;
- Disinfection: this type of treatment can be very well used to act as a disinfectant and microorganism eliminator simultaneously to chemical degradation;
- Reactions of organic compounds with reactive species: studies show that this type of processing is very fast, allowing the establishment of projects in irradiation system with good process flexibility;
- Reduction of environmental impacts: it is a safe alternative technique to minimize environmental impacts and contribute to environmental sustainability;
- Possible use of treated effluent as water reuse: a major advantage of this technological process is that it is possible to use water from treated effluent and reuse water for washing streets, garden and industrial processes;
- Association with traditional system: it is even possible to use this technology together with conventional treatment system of industrial effluents;
- Technical feasibility: occurs mainly in wastewater system where there is not a specific and efficient treatment technology and

- Accessibility: there is the possibility to use a mobile unit using electron accelerator for wastewater treatment, which can move up to companies to treat theirs effluents and demonstrate the technology.

3.6.CONCLUSION

The possibility of applying this technique in SABESP and PETROBRAS has the advantage of minimizing potential environmental impacts, such as pollution of air, soil and bodies of water, minimizing possible damage to humans, increasing the useful life of treatment systems, the possibility of reducing cost, likely due to the reuse of water treatment, as reused water, and the possibility of industrial water consumption economy. Studies have shown a technological, environmental, economic, social, and competitive advantage for the country.

This technology has been extensively studied by many research centers in the world but the use of this technology into environmental area has been moved slowly because industry and government is always conservative in adoption of new process, especially when they cannot observe the efficiency and cost effectiveness of a treatment in a full scale facility. Nowadays, the main focus of the group is the construction of the mobile unit for demonstration the technology *in situ*.

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