Effluent Zero Release Concept—The Brazilian Experience

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Abstract: Water scarcity is pushing the government, industries and researchers to the development of new strategies for water and wastewater management. An approach aimed at the optimization of the water use and minimization of effluent generation was developed at the Centro Experimental ARAMAR (CEA), a nuclear research facility, located in the State of Sao Paulo, Brazil. Bench scale tests followed by a pilot plant treating effluents from some nuclear research facilities have shown the results leading to the conclusion that the effluent zero release concept is feasible. Based on the gathered data, a project of an integrated effluent treatment system focusing on water recovery and environmental effluent release reduction has been developed.

Key words: effluent; wastewater treatment; zero release
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1 INTRODUCTION

Brazil accounts for almost 13% of the available world freshwater resources[1]. However, since its freshwater resources are not uniformly distributed over the entire country, two kinds of water shortages are identified. One is related to weather conditions, particularly in the northeast region, far from the coast. The other is due to the ever increasing water demand occurring in highly urbanized and industrialized areas of southeast region, particularly in the State of Sao Paulo, which is periodically submitted to water use restrictions during the winter season. This situation has led to the establishment of stricter regulations in order to minimize water quality deterioration as well as water demand. The pay per use act has been implemented, implying in specific charges for water withdrawals as well as for effluent releases[2]. Looking for low demand, low impact strategies, the effluent zero release concept was considered as a proven tool for adequate water management under the conditions of water shortage prevalent in the country. The effluent zero release concept as define by Mierzwa[3] means: “A set of procedures are applied in order to allow for that one or more reclaimed effluent stream could be reused or disposed off, causing no damages to the receiving body with characteristics of without any negative impact to the environment”. Under this definition it should be understood that the zero release concept does not necessarily means that there will be no effluent discharge to water bodies, but that the effluent allowed to be discharged has a quality level which is, at least, equivalent to the quality of the receiving body. The feasibility of achieving the zero release concept has been evaluated at the Centro Experimental ARAMAR (CEA), a nuclear research facility.

For that purpose an experimental study has been performed on a bench scale followed by a pilot plant in order to gather the necessary parameters for designing an effluent treatment plant. All the research was developed at The Centro Experimental ARAMAR (CEA), which is a nuclear research facility that belongs to the Brazilian Navy in charge of developing nuclear technology systems for peaceful uses. CEA is located in the city of Iperó, about 62 miles (100 km) from Sao Paulo city, capital of Sao Paulo State. The facilities to be installed are aimed to the development of activities related to the nuclear fuel cycle, including uranium milling and enrichment, nuclear fuel fabrication and a nuclear reactor. Considering all the activities that will be developed at the CEA, it is expected the production of a large variety of effluents, some of which are contaminated with uranium.

2 EXPERIMENTAL STUDIES

The research on the effluent zero release concept was started with an evaluation of the processes that would be developed at the nuclear facility, as well as on potential technologies available for effluent treatment in order to proceed to the bench scale tests. The facilities chosen to represent the typical effluents from CEA were the Nuclear Material Characterization Laboratory

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(LABMAT) and the Pressurized Water Nuclear Facility (INAP). LABMAT is a laboratory that develops nuclear and ceramic materials which would be used for nuclear fuel production. It is also responsible for the characterization of these materials. INAP is a pressurized water reactor type facility, which will be used for research activities. Taking in account that these units were not operational at the beginning of this research, the composition of effluents from them was established based on preliminary data from the original project, allowing for the preparation of synthetic effluents using distilled water and analytical grade reagents. The composition of three effluents expected to arise from the facilities considered in the study is presented in Table 1.

Table 1 Characteristics of simulated effluents from LABMAT and INAP

Compound	Concentration (mg/L)		
	LABMAT	INAP 1	INAP 2
Ammonium	74.5	–	–
Chloride	304.0	406.0	–
Chromium	24.9	–	12.7
Fluoride	10.0	6.6	–
Nitrate	412.0	<1.0	–
Sodium	22.0	216.0	–
Sulfate	790.0	230.0	–
Uranium	6.98	–	–
Iron	–	11.9	14.4
Manganese	–	13.2	13.2
Calcium	–	96.9	–
Magnesium	–	34.5	–
Zinc	–	1.3	–
Silver	–	–	1.48
Cerium	–	–	6.0
Molybdenum	–	–	13.1
TDS	1545	1066	971
COD	<10	<10	541.3

Note: – means that the contaminant was not added to the synthetic effluent, because it is not expected to be present.

INAP 1 represents the effluent which is expected to be produced by the system operating at the Pressurized Water Nuclear Facility, including the effluent from a cooling tower, while INAP 2 represents the effluent which is expected to arise from a laundry facility.

The treatment processes chosen to be evaluated are chemical precipitation, reverse osmosis and evaporation and crystallization. In order to obtain the operational parameters for system design, a jar test unit had been used to perform precipitation tests and a small reverse osmosis unit to treat the clarified effluent produced. No testing had been performed on the evaporation/ crystallization process. The precipitation tests were performed using calcium oxide as a precipitant, together with an organic flocculation aid. To reduce Cr^{6+} to Cr^{3+}, sodium disulphide was applied to the LABMAT effluent in advance to the precipitation test. The efficiencies of the precipitation tests were evaluated in terms of uranium and chromium concentration abatement for the LABMAT effluent, manganese concentration for the INAP 1 effluent and chemical oxygen demand (COD) for the INAP 2 effluent.

After the treatment parameters were defined, larger volumes of each synthetic effluent were prepared and submitted to the precipitation process. The settled solids produced were centrifuged and the clarified effluents were characterized. Table 2 presents the characteristics of clarified effluent, which were, subsequently, submitted to reverse osmosis process as described bellow.

Table 2 Characteristics of the synthetic effluents after precipitation and clarification

Compound	Concentration (mg/L)		
	LABMAT	INAP 1	INAP 2
Ammonium	13.6	–	–
Chloride	418.0	431.0	–
Chromium	0.03	–	1.33
Fluoride	–	–	–
Nitrate	264.0	0.46	–
Sodium	639.6	335.4	–
Sulfate	1220.0	245.0	–
Uranium	<0.005	–	–
Iron	–	<0.05	<0.05
Manganese	–	<0.05	0.06
Calcium	91.8	73.8	591.2
Magnesium	–	52.5	–
Zinc	–	<0.05	–
Silver	–	–	0.06
Cerium	–	–	0.41
Molybdenum	–	–	9.68
Conductivity(1) (mS/cm)	5.5	2.02	4.6
COD	3.5	0	66.9
pH after neutralization	7.1	7.1	7.0

Note: (1) Conductivity measurement was used to replace TDS measurement.

For the reverse osmosis (RO) assays a small capacity unit furnished by the Membrane Filtration System Company was used for the RO tests. It consists of a high pressure pump, a pressure vessel containing a spiral wound thin film composite membrane for brackish water, a cartridge filter, a pressure control valve, and a pressure gauge.

After passing through the pressure vessel, the effluents were collected and samples of permeate were analyzed for 20%, 40%, 60%, 80%, and 90% of water recovery. Since a single pressure vessel was used, containing just one membrane module, the concentrated was recycled to the feed tank, in order to get high water recovery. The testing for all effluents had been developed considering the maximum water recovery. Table 3 shows the results obtained considering 90% of water recovery and the estimated volume arising from each facility. It also shows the water quality standards for a class 2 water body, according to the Brazilian legislation[4,5], from which the water will be withdrawn to supply CEA's demand.

The bench scale tests have shown that the proposed effluent zero release concept is achievable given that the effluent quality was consistently below the standards established under class 2. Based on these promising results, an effluent treatment pilot plant was designed and installed for treating the effluents arising from the LABMAT facility.

Table 3　Effluent quality after reverse osmosis processing with 90% of water recovery

Contaminant	Concentration (mg/L)				
	LABMAT	INAP 1	INAP 2	Mixture of the three effluents	Quality standard for a class 2 water body
Nitrate (as N)	11.0	< 0.1	–	< 0.2	10.0
Sulfate	4.94	2.78	–	2.40	250
Chloride	4.60	2.30	–	1.99	250
Sodium	50.3	7.31	–	6.64	–
Calcium	1.69	0.50	7.86	1.55	–
Chromium III$^+$	< 0.002	–	–	$<2.9\times10^{-5}$	0.5
Chromium VI$^+$	–	–	< 0.05	< 0.007	0.05
Fluoride	0.025	0.021	–	0.018	1.4
Ammonium (as N)	0.63	–	–	0.005	1.0
Manganese	–	< 0.05	< 0.07	< 0.05	0.5
Iron	–	< 0.05	< 0.05	< 0.05	5
Silver	–	–	0.003	$< 4.2\times10^{-4}$	0.05
Cerium	–	–	< 0.05	< 0.007	–
Molybdenum	–	–	0.18	0.026	–
Magnesium	–	0.156	–	0.132	–
Uranium	< 5.0 μg/L	–	–	< 0.04 μg/L	0.02 (Total)
Conductivity (μS/cm)	126.5	14.12	67.7	22.7	500(TDS)~250
PH	6.0	6.0	6.0	6.0	6.0 to 9.0
Expected volume (m^3/d)	1.35	135	22.5	158.85	–

3　LABMAT PILOT PLANT

The pilot plant, a system installed in a 300 m^2 area, contains all the equipment necessary to collect, to store, to treat, to monitor and to discharge the treated effluent. It includes four holding tanks for effluent storage, one transfer pump, one holding tank for the chemical precipitation process, one pump for sludge discharge, one centrifuge, a reverse osmosis system, and a wiped film evaporator to reduce the volume of the concentrate from the RO unit[6]. Fig.1 shows a flow chart of the LABMAT effluent treatment system.

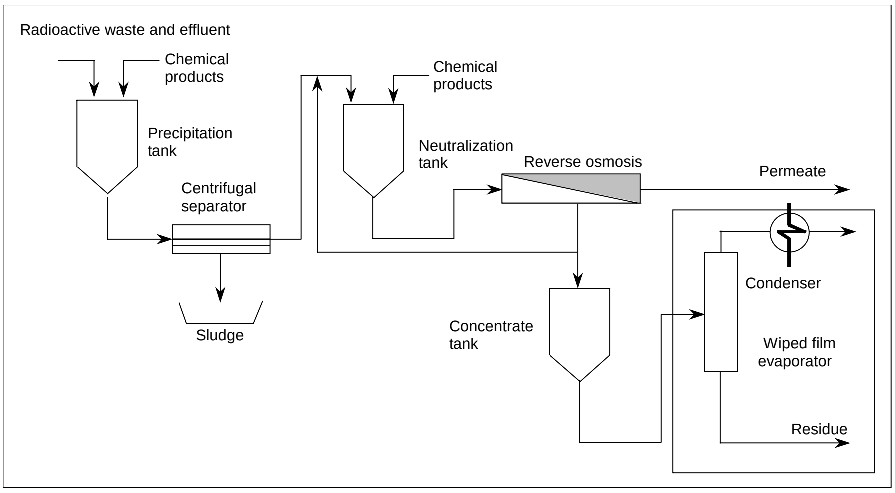

Fig.1 Flow chart of LABMAT effluent treatment system

In precipitation process some contaminants, such as metals, uranium and fluoride, were precipitated by adding calcium oxide. After precipitation a coagulant (polymer) was added to the precipitation tank to aggregate solids, allowing for its separation from the liquid phase. All the solids produced in this process are removed in the centrifuge, collected in a tray, and finally transferred to a drum which will be disposed off as industrial waste, if the uranium contamination level is below the limits established for the specific Radiological Protection Area, or it is disposed off as a low level radioactive solid waste. The clarified effluent is transferred to the neutralization tank for pH adjustment with hydrochloric acid, and then, processed in the RO system.

The permeate must have a very low concentration of contaminants, and after monitoring it could be recycled to LABMAT or released to the environment according to the standards established by the environmental local regulations. The LABMAT RO unit was designed with the following characteristics:

Salt concentration in the feed 1000~2000 mg/L;

Water recovery rate up to 90% of feed volume (global);

Salt concentration in the concentrate up to 20000 mg/L (maximum).

For the development of the activities related to the RO process, the unit at LABMAT is composed of two cartridge filters (10 and 5 m), a high pressure feed pump (up to 2000 kPa), four pressure vessels with Filmtec composite membranes for brackish water, a control panel, instrumentation, and a chemical cleaning system.

Considering the high water content in the RO concentrate, it was necessary to use a continuously fed vertical wiped film evaporator to concentrate the contaminants and recover the water. Due to the evaporation process, the salt concentration of the solution inside the evaporator increases, reaching crystallization at its bottom end and is collected in a drum.

The LABMAT wiped film evaporator is serving the purpose of assessing the evaporation performance in order to establish the best operational parameters that will be used for the design a full scale system. The main characteristics of LABMAT wiped film evaporator are presented bellow.

Feed solution: reverse osmosis concentration with a salt concentration of 2% (ω);

Capacity: 30 kg/h;

Volume concentration factor: higher than 25;

Heat source: steam;

Maximum steam flow: 50 kg/h (0.5 MPa);

Material: 316 stainless steel.

A representation of the LABMAT evaporation system is presented in Fig.2.

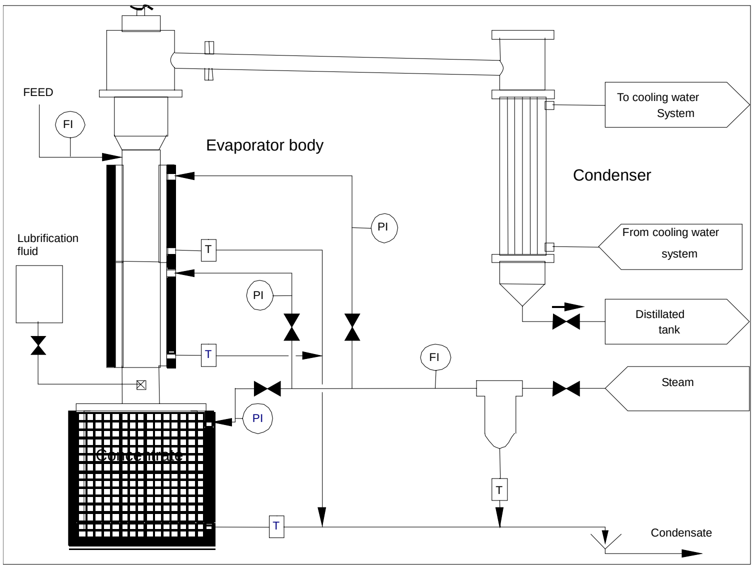

Fig.2 Flow chart of LABMAT wiped film evaporator

The results obtained in the LABMAT pilot plant verification tests are presented bellow.

For reverse osmosis unit:

Uranium removal: higher than 99.7%;

Decontamination factor for uranium: higher than 333;

Water recovery: 90%.

For wiped film evaporator:

Uranium removal: higher than 99.9%;

Ammonium removal: higher than 99.9%;

Total dissolved solids: higher than 99.7%.

After the evaluation of the LABMAT effluent treatment system performance it was decided to design a similar unit with a higher capacity to treat all the effluents arising from the CEA facilities. This system is the ARAMAR integrated effluent treatment system (SITEA), of which the main characteristics are presented in the next section.

4 SITEA CONCEPTION

The SITEA will treat all effluents from the CEA and will utilize, with minor changes, the same treatment techniques employed at the LABMAT effluents treatment system. As mentioned before the design of SITEA was based on the effluent zero release concept by assuming that the treated effluents will be used as industrial water. If there is no need for water reuse the treated effluent will be released to the receiving body after passing through a monitoring and releasing pond. Anyway, the effluent release to the environment will be done upstream the CEA's intake water, as a measure for guarantee that CEA is complying with the effluent zero release concept.

The SITEA has been designed to receive only inorganic effluents arising from all industrial facilities of CEA. Organic effluents produced at the plant are supposed to be treated by other means, before going to SITEA. Fig.3 shows a flow chart of the integrated effluent treatment system (SITEA). SITEA will have a capacity of 20 m^3/h in effluent treatment and it is expected to recover almost 98% of water contained in the effluents produced. This recovery rate will represent approximately 18% of the CEA's freshwater input.

Table 4 shows the costs of the effluent treatment considering capital as well as operation and maintenance (O&M) costs, according to payback times varying from 5 to 20 years.

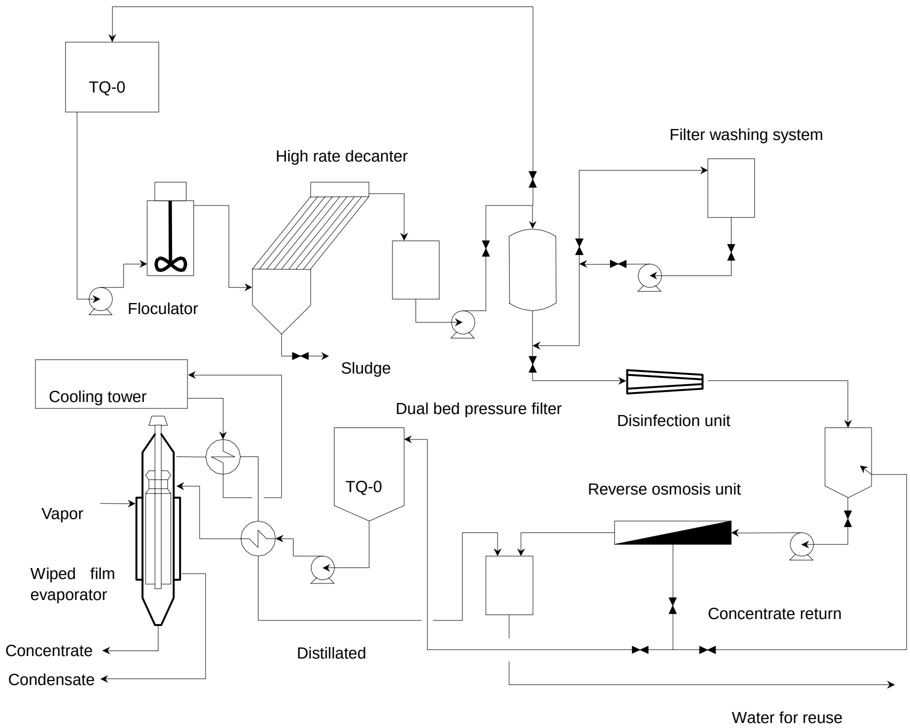

Fig.3 Simplified flow chart of SITEA

Table 4 SITEA effluent treatment costs

Payback period (year)	Treatment costs (US$/$m^3$)		Payback period (year)	Treatment costs (US$/$m^3$)	
	Intermittent	Continuous		Intermittent	Continuous
5	4.37	2.14	15	2.79	1.36
10	3.14	1.53	20	2.66	1.30

Note: O&M costs are concerned with 10% of the investment cost per year, 10% interest rate per year, 20 m^3/h throughput, 16 h/d intermittent operation and 22 days per month.

4 CONCLUSIONS

Based on bench scale testing and the results provided by LABMAT pilot plant, it can be concluded that the zero release concept is feasible. This conclusion is supported by the data gathered from the experiments performed and its comparison with the quality standards for a class 2 water body, according to the Brazilian legislation. After these promising results it was decided to develop an integrated treatment effluent system (SITEA), aiming to the production of effluents under the zero release concept in order to reuse the treated effluents as industrial water, or to provide effluent discharges which are not harmful to the environment.

The zero release approach demonstrates that technological development and environmental protection can be put together, even when effluents are originated from nuclear plants. Achievement of good results only depends on the commitment of engineers and researchers on the development and adoption of adequate concepts and technologies based on treatment efficiency and environmental sustainability.

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