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Barcelona, three years of experience in brackish water desalination using EDR to improve quality. New O&M procedures to reduce low-value work and increase productivity

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ABSTRACT

The 4.5 million inhabitants of Barcelona and the surrounding area are mainly supplied with surface water from the Llobregat and Ter river basins. The Llobregat river water shows important concentrations of parameters associated with salinity (Na^+, K^+, Cl^-, and Br^-), due to both natural and anthropogenic processes. Furthermore, many problems are associated with the increase in micropollutant and microbiological levels due to both urban and industrial sewage. These problems produce many interruptions of the process, some of them lasting many hours. As a consequence, the high levels of bromide (ranging between 0.5 and 1.2 mg/L), natural organic matter and temperature (T) produce high concentrations of trihalomethanes (THMs) after chlorination, showing a high brominated profile. To minimize the THMs problem, in 2009, the water utility Aigües Ter-Llobregat (ATLL) introduced a new technology based on a membrane process in the Llobregat-Abrera Drinking Water Treatment Plant (DWTP): a new Electrodialysis reversal (EDR) step. The DWTP can process up to $4\,m^3/s$ with conventional treatment including: pre-oxidation with potassium permanganate, coagulation, flocculation, oxidation with chlorine dioxide, sand filtration, granular activated carbon (GAC) filtration and final chlorination using NaClO. The EDR process takes feedwater after the GAC step by means of a derivation of the filtered water pipeline and can produce up to $2.2\,m^3/s$. Thus, this is the world's largest desalination plant using this technology, and a good example of a large-scale application of a desalting technology to improve the quality of drinking water. The EDR step operates discontinuously to optimize the energy consumption of the whole process, according with the expected levels of THMs in the outlet DWTP water. Due to the large size of the industrial plant, some studies have focused on improving operation and maintenance (O&M) work. Some O&M procedures are qualified as "low-value work," because they do not need any special worker qualification or because they are very repetitive. This can be a problem in the operation of a large plant, and some effort should be taken to assess the quality of life of the workers and to increase their productivity by improving safety and avoiding overwork, stress and burnout. Then some specific operations like assembly and disassembly of stacks, washing membranes and spacers, measuring inter-membrane voltages and "hot spot" detection will be simplified using specific tools. In this sense, ATLL introduced some new specific devices developed by the R&D department with good results from the point of view of the workers and the team

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managers. This study shows the operational and quality results after three years of full-scale plant operation and the improvement of the O&M procedures implemented.

Keywords: EDR; Brackish water; THM; Bromide; Low-value work

1. Introduction

Operation and maintenance (O&M) procedures are very important tasks, especially in large industrial facilities. In our case, the Llobregat-Abrera Electrodialysis reversal (EDR) plant is the largest in the world using this, and there is not enough information available related to management and O&M procedures at this level. In other large plants using membrane technologies like Sea Water Reverse Osmosis, it is possible to find more management information, but O&M work could be very different. The EDR is a robust technology when applied to brackish water desalination [1,2] and, after three years of operation, presents a good hydraulic recovery (higher than 90%), a good salt reduction level in function of temperature [3] and a low energy consumption in the EDR process ($0.5\,kWh/m^3$).

Moreover, the EDR technology has some technical characteristics related to the membrane stack that implies specific maintenance work [4]. In our case, these operations are very difficult to schedule due to the discontinuous plant operation. Thus, the EDR process is related to the expected THMs level at the end point of the DWTP, which shows higher values during the summer period. For this reason, the plant operation ranged from 1 to 9 EDR modules according with the volume needed to blend product water with conventional treatment flow at the end of the process line. Although plant monitoring and operation is fully automated with a supervisory control and data acquisition system (SCADA), many maintenance operations could be easy but manual and routine. To minimize the problem of a possible headcount overwork, the number of workers are gradually increased seasonally according to the expected production. Usually, during the winter period the operation headcount is of 10 people (5×2 shift) for operations and preventive maintenance and five more workers related to general maintenance, laboratory and management. In the summer, the operation team can increase up to 24–30 people.

Aigües Ter-Llobregat (ATLL) tries to avoid high workload, reducing stress, driving out low-value work, optimizing existing human resources and improving work-life effectiveness. The final target is to increase employees' time and energy for focusing on high-priority work. But it is very difficult to minimize some important (and sometimes underestimated) maintenance operations, like those related to daily monitoring and equipment inspections (look, listen, leaks, vibration analysis, data control …). Nevertheless, it is possible to work in reducing the specific tasks related to the technology. In this sense, ATLL has worked by means of its R&D department on the design and development of specific devices mainly related to the membrane stack system that reduces low-value work and optimizes headcount.

2. Plant operation

The DWTP plant is operated by the water utility ATLL, and the EDR step started up its operation in a test run in June 2008, begun normal operation in April 2009. Till now, the EDR step has produced more than $60\,hm^3$ of desalted water.

The DWTP can process up to $4\,m^3/s$ with conventional treatment including: pre-oxidation with potassium permanganate, coagulation, flocculation, oxidation with chlorine dioxide, sand filtration, GAC filtration and final chlorination using NaClO. This process does not affect the salinity of the water [5] and high levels of THMs are formed after outlet chlorination in the distribution system, when regulated maximum level is of $100\,\mu g/L$ for total THMs. After GAC filtration, it is possible to process up to $2.3\,m^3/s$ (58 MG/day) by means of an EDR brackish water desalination plant. The EDR step operates discontinuously to optimize the energy consumption of the whole process, according to the expected levels of THMs in the outlet plant water. Then, EDR treated water can be blended with the conventional product or can be distributed directly to the system. In the last case, a specific post treatment of the EDR effluent using a remineralization step could be necessary to meet Spanish regulation [6] This step will be used when required and is accomplished using $Ca(OH)_2$ and CO_2 addition to increase the Langelier Saturation Index of the water prior to distribution.

The EDR process includes a cartridge filtration (18 filters with 170 cartridges each, of 50 inches length and $5\,\mu m$ nominal size) and nine modules of EDR with two hydraulic EDR stages, equipped with a total of 576 EDR stacks of 600 cell pairs each one, which constitute the world's largest plant using this technology.

Every module is provided with reversing systems of flow for the changes of polarity, automatic valves and pumps that allow a fully automated system. The EDR process is operated according to the levels of THMs expected in the final drinking water. Then 1–9 modules are operated when necessary to blend the obtained water with conventional treatment product to maintain THMs levels at the lowest possible cost.

Each EDR module is equipped with 165 automatic valves, 86 mechanical valves, 64 flow meters, 1 pHmeter, 1 thermometer, 21 pressure controls, 4 conductivimeters, 23 module sampling points, 128 stack sampling points, 8 rectifiers to convert alternating current power to DC power and 4 amperemeters. Additionally, each one of the 64 stacks of each module has two specific sampling points. Data are collected or logged for the different streams and during positive or negative polarity.

Additionally, the operation team is involved in chemical operation including continuous hydrochloric acid dosing at the electrode compartment and periodically for the clean in place (CIP) procedures. Other chemicals included are antiscalant, NaCl and NaClO.

After the production of 60 hm^3, the EDR process presents consolidated data. Thus, the EDR step reduces the contents of significant parameters from GAC filtered water. The reduction values were (monthly analysis 2009–2011 expressed in percentage as average ± std): bromide: 77 ± 8%, chloride 76 ± 8%, NO_3^-: 74 ± 6%, sulfate: 72 ± 8%, Ca^{+2} > 84 ± 10%, K^+: 74 ± 9%, Mg^{+2}: 82 ± 7%, Na^+: 56 ± 12%, conductivity: 69 ± 9% and TOC: 30 ± 12%. Moreover, this salt reduction modifies the taste of the water and improves the esthetic assessment by the consumer [7].

3. Maintenance and workload

The EDR system is designed with a fully automated SCADA system. Thus, O&M procedures are scheduled to check control settings and operating parameters, supported with detection systems that recognize operation levels or critical conditions.

The EDR plant has two maintenance teams. The first is dedicated to the maintenance of the industrial devices, like pumps, flow meters, automatic valves equipped with actuators or general equipment: chemicals, lights, overhead cranes … and all the electrical and power services. The second one is the operational team which is allocated to operation and daily maintenance.

The workload of the two teams is very different. Both of them carry out specific work, but the work of the maintenance team is more discontinuous and includes more corrective maintenance operations. Some of this work needs specific external collaboration.

The operational team does more continuous work and includes operation control and supervision using the SCADA system. Their work is related to monitor process instrumentation and EDR stacks procedures. Several set points are implemented to operate the system. In this sense, operators check the values and alarms related to temperature, conductivity, pH, current voltage, intensity, flows and pressures, change cartridge filter and carry out the chemical cleaning (CIP). Routine preventive maintenance will ensure efficient operation as well as a long and reliable service life.

There is a mix of high- and low-level work, and in most cases, data are collected or logged for the different streams for 20 min by modules, to check the period of positive or negative polarity. This fact together with the plant size and the seasonal production creates a complex work environment.

For this reason, ATLL emphasize the factors in the work environment as well as work practices and processes that can have a negative impact on resilience and contribute to overwork, stress and burnout. Among these factors, we include the analysis of: monotony, under-stimulation, meaningless tasks, lack of variety, too much or too little to do, work under time pressure, pace, hours, methods, etc.

4. Reducing "Low-value work" using specific devices

ATLL is concerned about the impact of workload on employees and managers, mainly due to the plant size and to its discontinuous operation. Thus, company efforts have been directed to minimize the low-value work, specifically related with the EDR technology. In this way, some work of the R&D department has been focused on the design and development of special devices to use in three areas involved in the operational maintenance:

- Stack probing.
- Cleaning membranes.
- Stack repair and disassembly.

4.1. Stack probing

The most frequent manual operation is to check the inter-membrane voltage to prevent "hot spots" or current leakage. The inter-membrane voltage has to be similar throughout the entire stack, and operators have to check it each 200 h. Excess current can melt or "burn" the membranes and spacers. Normal design practices limit this voltage to 80% of the current that would case burning. The limit is determined by water temperature, conductivity of the source water, membrane stack size and the internal manifold that splits flow into concentrate and dilutes streams. When operators find increases of current in a located point, they have to check the voltage for some days to prevent a "hot spot."

Standard operation requires two people to check 56 points in each stack and in each polarity. They then have to manually refill the log sheet, and later, they must introduce the information using specific software. So, we can define this procedure as low-value work, because it is routine, monotonous and very manual. Additionally, the work needs special attention for safety conditions.

Thus to facilitate the work, the stack probing is now improved with a new device (Fig. 1) that identifies each position with an radio-frequency identification label and measures three points each time, reducing the time operation from 2 people/16 h/module (total 32 h) to 1 person/12 h/module (total 12 h). Then, the correct data are introduced into a structured query language database, avoiding mistakes. The new equipment incorporates pre-programed non-critical alarms to indicate any anomalies in the stack.

4.2. Cleaning membranes

One of the advantages of the EDR technology in comparison with other membrane technologies is its ability to troubleshoot by opening and disassembling the stacks. In the case of problems like biofouling or scale, each unit (membrane or spacer) can be washed manually, brushing with diluted chemical products.

Usually, if no problems are found, we wash each first-stage stack once a year, as preventive maintenance work, which includes inspection and washing process. This involves washing 2,400 units for each of the 288 stacks, only in the first stage. So this procedure can also be defined as low-value work, because it is routine, monotonous and very manual. A specific washing machine (Fig. 2) is now available to wash the membranes and spacers (2.6 units/min), reducing this "low-value cost" operation.

4.3. Stack repair and disassembly

During maintenance procedures or when a problem arises, it might be necessary to disassembly the stack, due to wash procedures or reparations. Generally, disassembly requires that each piece be removed separately, with the exception of the top electrode, which can be replaced without the removal of any of the membranes.

In some cases, the operator finds a "hot spot" and an area of the stack can be burned. It is then necessary to disassembly the stack to reach to the affected units and wash or replace them.

In this case, ATLL has designed a robotic device that can assemble and disassemble a stack (2.5 units/min). A computer program allows operation until a pre-programed position of the stack. The operator can then check the problem and repair it. Then the

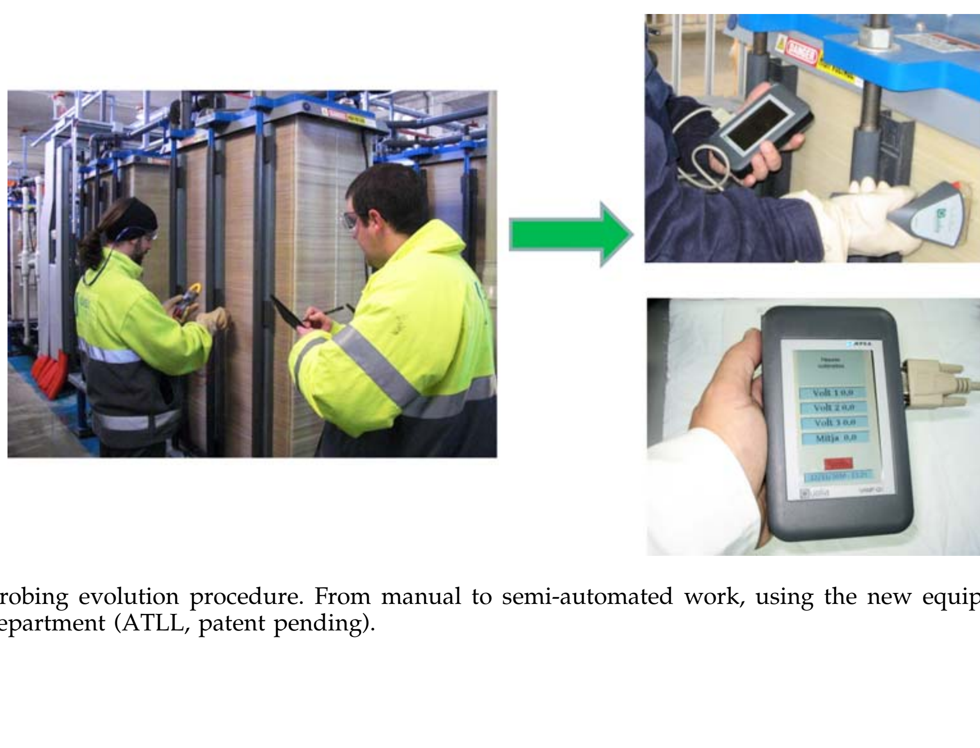

Fig. 1. Stack probing evolution procedure. From manual to semi-automated work, using the new equipment developed by the R&D Department (ATLL, patent pending).

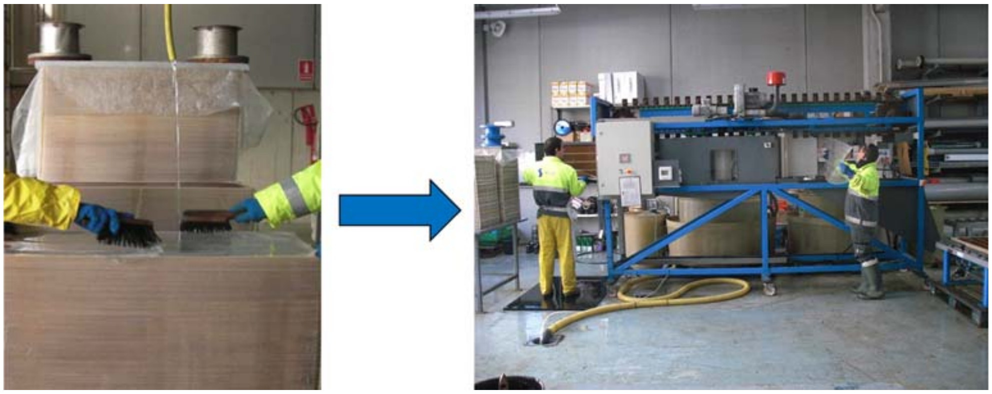

Fig. 2. Evolution of the process of wash. New washing machine developed by the R&D Department.

Fig. 3. Robotic device for assembly and disassembly the EDR stack.

machine can assemble the stack in the correct position. It is important to maintain correct component orientation and to store membranes in water. The stack should be rebuilt in the order it was disassembled; incorrect assembly can reduce performance or cause scaling. Normally, this manual operation requires two people, and it is possible to perform an incorrect assembly. The new machine (Fig. 3) needs only one supervisor equipped with a tablet computer, which the low-value work is further reduced.

5. Conclusions

- The Llobregat-Abrera DWTP near Barcelona includes a EDR step and it represents the largest plant of the world to use this technology. Working with a large plant equipped with the start-of-the art technology has several advantages, particularly related with its level of automation. However, there is a little information about O&M procedures.
- The plant process is discontinuous and seasonal, which makes difficult to schedule O&M procedures and to have workers ready and motivated for the changes in the workload according to the production requirements.
- EDR technology has a lot of procedures related with operational maintenance that are very routine and monotonous, which can be named "low-value work."
- ATLL has carried out some R&D studies to design and develop some specific devices to use in three areas involved in the operational maintenance:
  - Stack probing.
  - Cleaning membranes.
  - Stack repair and disassembly.

These devices are focused on reducing "low-value work" and employee stress and burnout. Thus, workers can have more time and energy for dedicating to high-priority work. Additionally, the new equipment reduces operational costs.

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