RESEARCH AND RESULTS REGARDING ENVIRONMENTAL PROTECTION DURING THE REVERSE OSMOSIS USED FOR THE TREATMENT OF WASTEWATER FROM URANIUM PROCESSING

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ABSTRACT :*This paper presents the reverse osmosis plant, as part of the wastewater treatment plant resulting from the uranium ore preparation plant in Feldioara. Are presented the overall constructive solution of the plant, construction and operation of filtration membranes as actuators providing superior operating parameters for the entire plant, the figures of the technological calculation for plant sizing and the main operating conditions.*

KEY WORDS: osmosis, uranium, filtration, parameter

1. General overview

Osmosis is the transfer of a solvent through a membrane under the effect of the gradient's concentration of a solution. If we consider a system formed by two compartments separated by a semi-permeable membrane containing two solutions of different concentrations, the direct osmosis occurs through a stream of water directed from the dilute solution into the concentrated solution.

If pressure is applied on the concentrated solution, the amount of water transferred will be diminished. For a sufficiently high pressure, the water flow will be canceled, this pressure being called osmotic pressure, p_0. If it exceeds the osmotic pressure then it's performed a reverse controlled water flow. This phenomenon is known as reverse osmosis. The phenomenon of osmosis is represented graphically in Figure 1. Osmotic pressure, p_0 in Pa, is calculated with

$$p_o = i\,C\,R\,T\ ,\ Pa \qquad (1)$$

where: *i* is the number of existing ions types in solution, *C* - molar concentration of concentrated solution, mol/m3; *T* - temperature, *K*; *R* - perfect gas constant, J/(mol K). This relationship is valid for dilute solutions.

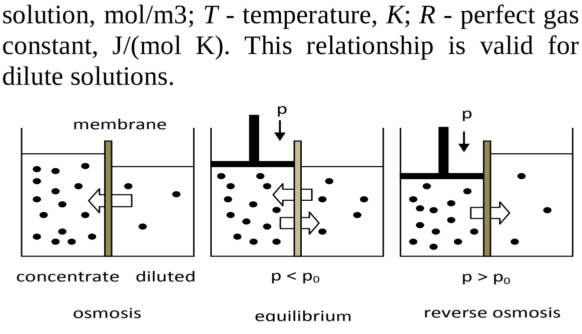

Figure 1 The principle of osmosis phenomenon

Based on this principle was designed, made and put into operation a reverse osmosis plant, which is part of the treatment plant of wastewater resulting from the uranium ore preparation at the plant in Feldioara. The parameters that are influencing the functioning of the reverse osmosis plants at a higher level are: pretreatment with chemical reagents; membranes state; working pressure; water temperature; salt content in water; efficiency.

2. The design and functioning solution of the reverse osmosis plant

The reverse osmosis system is based on the same name principle. It consists of a dosing installation for the antiscale and reducing reagents and feeding flush water from three reverse osmosis batteries in series RO1, RO2, RO3, plus filter module FO from the final concentration station.

Figure 2 shows a schematic constructive and functional diagram of raw water supply system, clean water and chemical reagents dosing of the three batteries.

RO1 reverse osmosis system, Figure 3, consists of 21 pressure tubes with a diameter of 8" made of composite material, loaded with 7 membranes each and arranged in two stages. The first stage or transition consists of 14 pressure tubes fed in parallel, and the second stage consists of seven pressure tubes in series with the first 14. Following the passage of waste water across the membrane results a concentrate and permeate. The concentrate, which represents about 23% of the initial raw water flow is routed to an intermediate basin, where it is circulated with a pump at the reverse osmosis plant RO2.

The permeate with a flow rate of approximately 77% of the initial flow is directed to the 100 m^3 tank, which represents the storage tank of treated water that will be sent to the natural emissary. A part of permeate is directed to an intermediate tank which has pumps for the regular washing of the membranes. Approximately 10% of permeate flow are directed to the supply basin for RO2, to dilute the salts from the concentrate resulting from RO1.

RO1 battery is supplied with raw water resulting from ion exchange plant, through two pumps in series, of low and high pressure. A safety microfilter (control) is interposed between the two pumps with 50 interchangeable filter cartridges, with filter finesse $5 \mu m$.

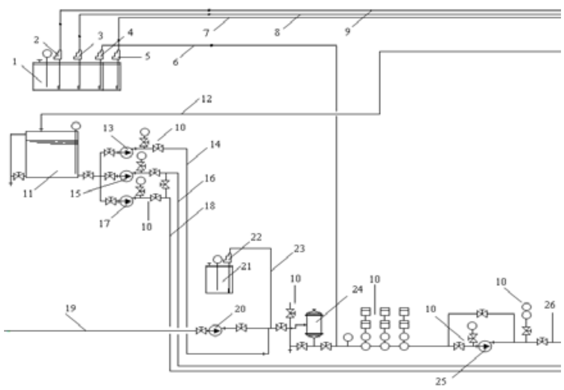

Figure 2 Constructive and functional diagram of raw water and chemical reagents feed

1 – antiscale substance tank; 2, 3, 4, 5 - dosing pumps for antiscale substance for RO2, RO3, RO1 and RO from the evaporation-crystallization plant; 6, 7, 8, 9 - pipes (PVC, stainless steel) antiscale substance for supply of RO1, RO from the evaporation-crystallization plant, RO2 and RO3; 10 - safety equipment, distribution, command and control; 11 - clean water tank from RO1 for used for washing the membranes; 12 - pipe for clean water from RO1; 13 - centrifugal pumps for clean water supply of RO1; 14 - pipe (PVC, stainless steel) for clean water RO1; 15 - centrifugal pumps for clean water supply RO2; 16 - pipe (PVC, stainless steel) for clean water at RO2; 17 - centrifugal pumps for clean water supply to RO3; 18 - pipe (PVC, stainless steel) to supply clean water to RO3; 19 - water pipe coming from ionization plant; 20 - centrifugal pump raw water supply to RO1; 21 - tank for bisulfate; 22 - reducing substance dosing pump for RO1; 23 - pipe (PVC, stainless steel) for reducing substance supply; 24 - safety filter (control); 25 - high pressure centrifugal pump (16 bar) for supplying RO1 (mixture of fresh water, clean water, reducing substances, antiscale substance); 26 - mixture supply pipe of RO1.

The washing of the membranes periodically occurs with washing pumps, this being necessary due to the pressure difference between the inlet and outlet of filtered water. To prevent the forming of crusts, on the membrane is dosed the antiscale.

To RO1, in the discharge pipe of the low pressure pump, is dosed sodium bisulfate solution, the role of this solution is to reduce, to eliminate the possible that microflora that would form on the membrane.

FO module assures the decrease of the amount of water that will be processed by evaporation-crystallization plant, respectively the increase of the salt content.

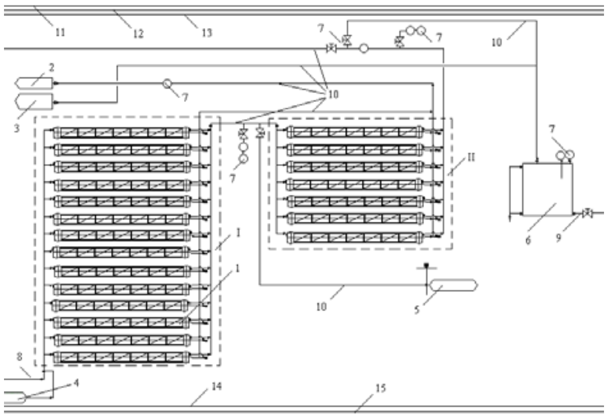

Figure 3 Constructive-functional diagram of reverse osmosis plant RO1

I - stage 1; II - stage 2; 1 - composite pressure tube with seven membranes (98+49 membranes); 2 - permeate RO1; 3 - at chemical wash tank; 4 – chemical rinse input; 5 - input / output chemical rinse; 6 – concentrate tank RO1; 7 - safety equipment, distribution, command and control; 8 - supply pipe (PVC, stainless steel); 9 – connection pipe with RO2 (PVC, stainless steel); 10 - pipeline connection (PVC, stainless steel); 11, 12, 13 - pipes (PVC, stainless steel) for antiscale dosing to RO3, RO2 and RO from the evaporation-crystallization plant; 14, 15 - pipe (PVC, stainless steel) with clean water for dosing the reducing solution to RO2 and RO3.

The reverse osmosis module consists of two pressure tubes, connected in parallel, and provided each with four special membranes to withstand high working pressures. The supply is achieved by two centrifugal pumps, the first of low pressure, which takes from the tank the water coming from RO3 (concentrate), the second pump is connected in series and increases the pressure to 80 bar required for membrane feeding.

Manufacturing operations and washings are provided automatically by the control system and PLC control, respectively automatic valves operated pneumatically. Sequence of operations is ensured by instruments mounted on technological lines, which indicate the value of the parameter measured, both locally and on PLC screen. The main features of the control system are: input / output of digital signals (levels, thermal differences, etc.); real-time indication of the values of all variables, analog inputs, views of messages and alarms. Connecting pipes are made of chemical corrosion and mechanical shock resistant PVC. Valves and related parts are made of corrosion mechanically resistant materials. In the case of high pressure water pipes is used stainless steel AISI 316, reinforcements being made of the same material.

Table 1 presents the normal operating parameters of the reverse osmosis batteries, including the osmotic filtration stage, FO, from the final module of evaporation-crystallization.

No	Parameter	MU	Parameter value			
			RO1	RO2	RO3	FO
1	Input pressure	MPa (bar)	0.2...0.3 (2...3)	0.2...0.3 (2...3)	0.2...0.3 (2...3)	0.2...0.3 (2...3)
2	Feeding pressure (high pressure pump)	MPa (bar)	1.634 (16.34)	3.863 (38.63)	5.081 (50.81)	8.055 (80.55)
3	Input flow	m^3/h	140.00	35.00	13.25	7.02
4	Permeate flow	m^3/h	107.80	22.75	6.23	2.18
5	Concentrate flow	m^3/h	32.20	12.25	7.02	4.84
6	Permeate conductivity	µS/cm	135.00	135.00	826.00	1200.00
7	Concentrate conductivity	µS/cm	26656.00	69460.00	126199.00	175000.00
8	Efficiency	%	77.00	65.00	47.00	31.00

the reverse osmosis batteries, including the osmotic filtration stage, FO, from the final module of evaporation-crystallization.

From this table, there is a tendency of variation of the main parameters which are characterizing the four osmotic levels, from where we can draw the following conclusions: pronounced increase of the supply pressure of the membranes, the pressure being created by high-pressure pumps, the increase being approximately 5 times; pronounced decrease of the flow, explained by the large number of the membranes existing in the RO1 battery; pronounced increase in conductivity, both for permeate and the concentrate, also explained by the removal from the first phase of a large amount of water; pronounced decrease of the efficiency of the reverse osmosis processes.

3. Characterization of membranes used in construction of the reverse osmosis plants

Quality level of a reverse osmosis system is mainly given by the filtering membranes. In the studied plants are used FILMTEC type membranes manufactured by Film Tec Corporation, a world leader in the production of filtering elements for reverse osmosis, equally to those used for nanofiltration. Spiral wrapped FILMTEC constructions are based on a membrane consisting of a thin FT30 composite layer.

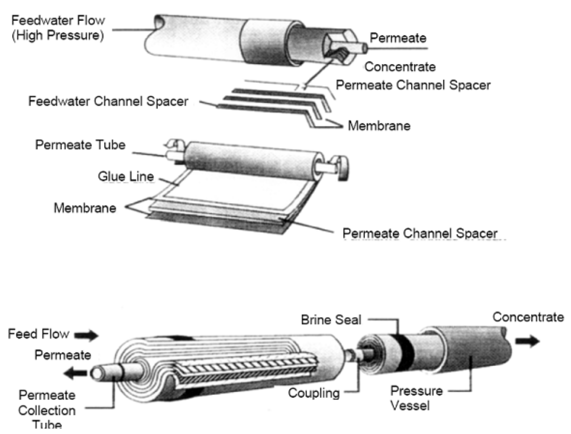

Figure4 Spiral construction of FILMTEC membranes

The membrane consists of three layers: retention layer (barrier) of thin polyamide; an intermediate layer of microporous polysulfone; a polyester support network with excellent strength characteristics.

The polyamide layer provides high flow and high resistance to chemical attack.

The microporous polysulfone layer is thick and has the characteristics of porosity and strength, resistant to compaction under high pressure.

The FILMTEC FT30 membrane is composed of thin layers of resistant to compaction, abrasion and chemical degradation.

Figures 4 and 5 present this type of membranes, from which eloquently results the components, their arrangement, suggesting their operating principle.

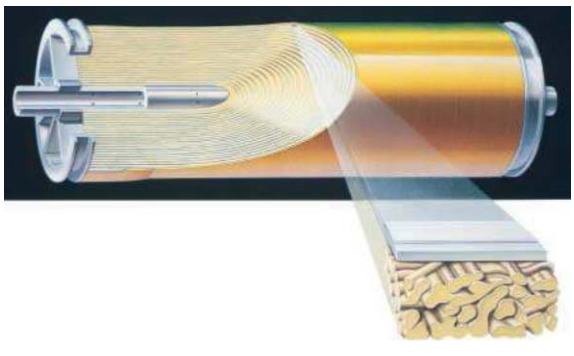

Figure 5 Section through a FILMTEC membrane

Table 2 summarizes the types of membranes used at the three reverse osmosis batteries, RO1, RO2 and RO3 with major functional features and installation.

Table 2. Technical characteristics of the FILMTEC membranes used at the reverse osmosis plant

<table>
<tr><th rowspan="2">No.</th><th colspan="2" rowspan="2">Plant</th><th rowspan="2">Membrane code</th><th colspan="4">Maximum working pressure, MPa (bar)</th></tr>
<tr><th>Maximum working pressure, MPa (bar)</th><th>Active surface, m²</th><th>Length, mm</th><th>Diameter, mm</th></tr>
<tr><td>1</td><td rowspan="2">RO1</td><td>Pass I</td><td>BW30-400/34i</td><td>4.1 (41)</td><td>37</td><td rowspan="6">1029</td><td rowspan="6">201</td></tr>
<tr><td>2</td><td>Pass II</td><td>LE-440i</td><td>4.1 (41)</td><td>41</td></tr>
<tr><td>3</td><td rowspan="2">RO2</td><td>Pass I</td><td rowspan="2">SW30HRLE-400</td><td rowspan="2">8.3 (83)</td><td rowspan="2">37</td></tr>
<tr><td>4</td><td>Pass II</td></tr>
<tr><td>5</td><td rowspan="2">RO3</td><td>Pass I</td><td rowspan="2">SW30ULE-400i</td><td rowspan="2">8.3 (83)</td><td rowspan="2">37</td></tr>
<tr><td>6</td><td>Pass II</td></tr>
</table>

From this table is remarked the very high active surface of a membrane, as well as the use of membranes with higher working pressure for RO2 and RO3 batteries.

4. Technological calculation abstract

Calculation abstract is performed using a specialized program, through which, using as input data the actual existing conditions, respectively the wastewater characteristics resulting from the preparation of uranium, the results have been simulated, concluded in numerical values of the pressures and flows of the permeate and concentrate resulting from the treated wastewater. In the tables presented below are presented the main results of the program for three reverse osmosis batteries.

It's stated from the start that following this technological calculation abstract was possible to determine the number of membranes needed to achieve the goal, depending on which were sized the other components of the reverse osmosis plants.

Table 3. Values of the main parameters haracterizing the RO1 system

<table>
<tr><th>No.</th><th colspan="2">Parameter</th><th>MU</th><th>Parameter value</th></tr>
<tr><td>1</td><td colspan="2">Supply flow</td><td>m³/h</td><td>139.98</td></tr>
<tr><td>2</td><td colspan="2">Waste water for system flow</td><td>m³/h</td><td>139.98</td></tr>
<tr><td>3</td><td colspan="2">Supply pressure</td><td>bar</td><td>17.80</td></tr>
<tr><td>4</td><td colspan="2">Clogging factor</td><td>-</td><td>0.85</td></tr>
<tr><td>5</td><td colspan="2">Dosing HCl solution</td><td>mg/l</td><td>143.47</td></tr>
<tr><td>6</td><td colspan="2">Active surface</td><td>m²</td><td>5644.60</td></tr>
<tr><td>7</td><td colspan="2">Permeate flow</td><td>m³/h</td><td>111.99</td></tr>
<tr><td>8</td><td colspan="2">Efficiency</td><td>%</td><td>80.01</td></tr>
<tr><td>9</td><td colspan="2">Temperature</td><td>ºC</td><td>15.00</td></tr>
<tr><td>10</td><td colspan="2">Dissolved solid substances</td><td>mg/l</td><td>4578.30</td></tr>
<tr><td>11</td><td colspan="2">Membranes number</td><td>pcs</td><td>147</td></tr>
<tr><td>12</td><td colspan="2">Passing speed</td><td>lmh</td><td>19.84</td></tr>
<tr><td>13</td><td rowspan="4">Osmotic pressure</td><td>Supply</td><td>bar</td><td>2.73</td></tr>
<tr><td>14</td><td>Concentrate</td><td>bar</td><td>12.91</td></tr>
<tr><td>15</td><td>Average</td><td>bar</td><td>7.82</td></tr>
<tr><td>16</td><td>NPD average</td><td>bar</td><td>10.41</td></tr>
<tr><td>17</td><td colspan="2">Power</td><td>kW</td><td>86.54</td></tr>
<tr><td>18</td><td colspan="2">Specific energy consumption</td><td>kWh/m³</td><td>0.77</td></tr>
</table>

5. Operating conditions of reverse osmosis plant

Reverse osmosis system is so designed that requires minimal attention from the user. Like any mechanical system, a regular and appropriate maintenance ensures a correct operation.

Maintenance operations are limited to: adjusting and recording operating parameters; check the feed water pretreatment; preparation of chemical reagents; replacement of the filter cartridges when necessary; periodically check the accuracy of the measuring instruments indications; washing and disinfecting the membranes, if necessary.

Water that enters in the reverse osmosis units must be clarified and disinfected. Although this is not essential in the operation of reverse osmosis plants, the pre-osmotic quality directly decides the recovery and useful life of reverse osmosis plants.

In the first part of the reverse osmosis plant, conditioning chemical products are injected into the pipeline. These products have two main objectives: adding antiscale to avoid precipitation of various salts, because of the movement of water through membranes, the solubilization conditions being different, the risk of precipitation (crystallization) is increased. Sulphate and carbonate precipitates on the membrane is the main source of crusts forming; adding antioxidant which eliminates the free chlorine that may be present in raw water and can oxidize the active layer of the membrane; adding sodium bisulfate solution, its role being reductant, respectively eventual elimination of microflora that would form on the membranes.

After dosing the reagents, the water passes through a control microfilter with interchangeable cartridges with filter fineness of 5 μm, which retains particles potentially harmful to membranes. It is mandatory to frequency change the cartridges. Cartridges cannot be washed and reused.

During commissioning of the system, the following sequence must be done: opening the supply valve; simultaneous command to dose the reagents in the supply pipe, activating the metering pumps for reduction and antiscale; starting the low pressure pump; progressive starting of the high-pressure pump; during initial startup will specifically check the opening of the ventilation valves of the reverse osmosis systems located In the microfilters housing, at the top of high pressure tubes and wherever control instruments with safety valves are fitted, which are used for ventilation.

It is possible that the water quality produced is not maximum for a period of time after commissioning. This phenomenon is typical for the reverse osmosis plants and is not a reason for concern, only if the necessary time is excessively long.

In case of shut down, the sequence runs inverse: progressing shut of the high-pressure pump; shut down the low pressure pump closing the intake valve; shut down the antiscale dosing pump, with the pump for reducing still operating; opening the flush valve; starting the flush pump, stopping the flush pump; stopping the reducing pump; closing the flush valve.

By consulting the monitor from the control panel, can be detected if the system is in a final operating sequence, if is in a normal operation or it was an alarm situation. In this case, execute the corresponding adjustment in the minimum time.

The reverse osmosis plants are complex systems, which strongly influences the physical and chemical characteristics of water. It's not recommended their stop for prolonged periods, because there is a risk of crust formation. The supply of electricity won't be stopped only when absolutely necessary and for a very short period of time.

Simplicity and automation are key aspects of designing the reverse osmosis systems. For this purpose, was developed a control system specifically for these facilities, which controls all operations required for normal operation.

The control system switches the system on and off, detects and views the alarm situations and informs the user about the process parameters and important operational data.

6. Conclusions

The reverse osmosis plant is part of the wastewater treatment plant, wastewater that results from the preparation of uranium ore, the liquid fraction resulting from processing the contaminated water in this plant can be discharged into the environment.

The system consists mainly of four parts, a chemical reagent dosing system and supplying clean water to wash the membranes and three reverse osmosis batteries RO1, RO2 and RO3.

RO1 filter battery is characterized by two processing steps (stages) in series. The first stage consists of 14 pressure tubes connected in parallel, made of composite material, each containing seven membranes and the second stage of seven tubes connected in parallel, resulting in overall 98+49 membranes with a filtration area of (3626+2009) m^2. Supply pressure is 16 bar, permeate and concentrate flows are of 108 m^3/h and 32 m^3/h, efficiency, considered to permeate, reaching 77%. RO2 filtering battery with a efficiency considered to permeate of 65%. RO3 battery filter with efficiency is 47%.

FO filter module is characterized by two high pressure tubes mounted in parallel, each with four membranes (8 membranes). Supply pressure is 80 bar, permeate flow of 2 m^3/h, concentrated flow of 5 m^3/h and efficiency in permeate is about 28%.

The technological calculation performed using a specialized program based on quality characteristics of raw water to be processed, has led to establishing the necessary of filtration membranes on each battery and stage.

The reverse osmosis system is so designed that requires minimal attention from the user.

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