A SMART INNOVATION IN SEAWATER DESALINATION (ERI PX DURABILITY & CORROSION RESISTANCE)

CHELLOU Nassir*, MOUDJEBER Djamel Eddine, MAHMOUDI Hacene

*Department of Mechanical Engineering, Faculty of technology, Hassiba Benbouali University of Chlef, Algeria, * meca.indu@hotmail.fr*

Abstract

Every year, around 300 million m^3 of seawater is desalinated & lots of researches are involved in the same domain. Various methods & techniques were invented to rise up the level of water purity. One of the largest used techniques in this domain is the Reverse Osmosis, which is a simulation to the natural phenomena called Osmosis that depends on high pressure pumping of the conducted seawater to the RO modules, in order to desalinate the water from salt. However, obstacles were always facing researchers during the realization & also preventing the dispositive from damage while facing the immense seawater pressure (50 to 62 bars). But the worst obstacle is corrosion problem! Due to the high salt concentration in the seawater, what did extend the challenge to find more solutions to increase the yield & decrease the energy consumption with assuring a long-life for desalination dispositive. In 1992, Energy Recovery, Inc.(ERI) was established and manufactured ultra-high efficiency recovery products and technology, specifically the ERI Pressure Exchanger (PX) that is among the enabling technologies driving the rapid growth in seawater reverse osmosis (SWRO) using the alumina Al_2O_3 , known with a thick oxide layer that protects the metal from oxidation. For the first time, a predicted design of the ERI pressure exchanger's geometry was built, analyzed & verified with a numerical simulation to show the long life time of the ERI PX (up to 20 years & more) & explain the strength, high pressure & corrosion resistance of its forming materials.

Keywords: Pressure exchanger, corrosion resistance, seawater desalination

1. INTRODUCTION

In the seawater desalination industry, energy efficiency is a key component when evaluating the economics of a plant. In the SWRO process, power consumption is the largest component of the entire process accounting for an estimated 30-40% of the total RO portion. Energy recovery devices were developed primarily for this reason- to reduce energy consumption by as much as 60 percent [1]. By significantly minimizing energy costs, plant owners can positively impact the economics of their operations, In addition to combat the challenge of facing corrosion problems, especially when we are dealing with seawater. For this ERI's PX is mainly constructed with Alumina ceramics, to give a better performance, good efficiency & avoid corrosion problems, to extended the PX life time to more than 20 years, what makes ERI's company the leader in the world of desalination.

2. THE PRESSURE EXCHANGER

2.1. Definition

A PX is a kind of fluid energy recovery equipment which is based on the positive displacement principle. The key components of PX include a rotor with several circular ducts, two end covers and one sleeve. At any time during operation, half the ducts are exposed to the high pressure fluid and the other half are exposed to the low pressure fluid. There are two indispensable requirements for PX when used in SWRO [2].

The concentration of fresh seawater at high pressure outward pipe should not be so increased that it will have bad effect on the RO.

The high pressure system and low pressure system in PX should be completely separated; otherwise the leakage will happen and lead to the energy recovery efficiency decreases dramatically.

PX devices are positive displacement isobaric devices commonly used in SWRO processes built since 2003 [3]. Pressure transfer occurs through direct contact between the high-pressure concentrate and pressurized seawater inside the devices. Because there are no pistons or barriers in the flow paths, high- and low-pressure flow rates through the devices can be manipulated freely.

2.2. Working principle

The PX unit uses the principle of positive displacement to pressurize filtered feedwater by direct contact with the high-pressure concentrate (waste) stream or the reject fluid from an RO system. Pressure transfer occurs in the longitudinal ducts of a ceramic rotor that spins inside a ceramic sleeve. The rotor-sleeve assembly is held between two ceramic end covers. At any given instant, half of the ducts are exposed to the side with high-pressure fluid and half are exposed to the side with low-pressure fluid. As the rotor turns, ducts pass a sealing area that separates the high-pressure side from the low-pressure side. This process is illustrated in the figure bellow [4].

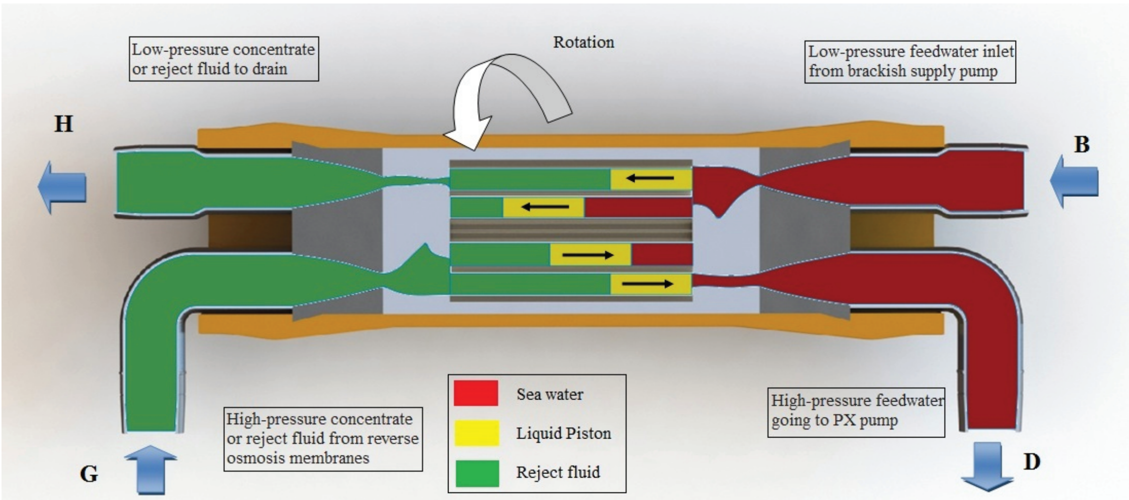

Figure 1 Process of the Pressure exchanger

Feedwater pumped from the brackish water supply at low pressure flows into a duct on the left side of the figure. This flow expels concentrate from the duct on the right side of the figure. After the rotor turns past a sealed area, high-pressure concentrate flows into the right side of the duct, pressurizing the feedwater. Pressurized feedwater then flows into the high-pressure feed line going to the PX pump. This pressure-exchange process is repeated for every duct with each revolution of the rotor such that the ducts are alternately filling and discharging. At a speed of 1200 rpm, one revolution is completed every 1/20 of a second. **Figure 1** shows the flow path of a typical RO-PX system. The concentrate from the RO membranes (G) passes through the PX, where its pressure is transferred directly to a portion of the incoming feedwater at up to 91% efficiency. This pressurized stream of feedwater (D), which is approximately equal in volume and pressure to the reject stream, passes through a PX auxiliary pump (not the main high-pressure pump) to add back the small amount of pressure lost from the differential pressure across the membranes and from friction in the piping and the PX. The PX recirculation pump drives the flow through the high-pressure side (G and D) of the PX. Fully pressurized feedwater then merges with the main feedwater line of the RO system after the main high-pressure pump. In an RO-PX system, the main pump is sized to equal the RO permeate flow plus a small amount of rotor lubrication flow, not the full RO feed flow. Therefore, the PX significantly reduces flow through the main pump. This point is significant because a reduction in the size of the main pump results in lower power consumption and operating costs [5].

2.3. 3D modeling of the PX

The technology does not directly relate to filtering water, but instead harnesses the pressure in the wastewater stream of reverse osmosis systems and transfers that pressure to the incoming feed stream to reduce the energy required to run the desalination process [5]. Basing our research on multiple parameters, we could model the geometry of the PX as presented in **Figure 2**.

Figure 2 3D modeling of the Pressure Exchanger

The PX is designed in a way to be subjected to high compression constraints due to the pressure that varies from 50 to 60 bars, & to high torsion constraints due to its angular velocity of 125.66 rad/sec (1200 round/min). The matter that makes ERI's PX technology the leader in the world of desalination nowadays.

2.4. Perspective view of the Pressure Exchanger

As shown in **Figure 3**, the PX has a housing containing a rotor with a plurality of channels. A low pressure seawater feed stream from a reverse osmosis system is pumped through a straight inlet conduit and fills an inlet passageway. At the same time, high pressure brine from the reverse osmosis system is pumped through an elbow conduit, fills a plenum chamber and enters axial channels, causing the rotor to spin. As the rotor spins, there is periodic alignment of each channel with the opening to a discharge seawater passageway in an upper end cover [5].

Thus, the pressurized seawater is caused to flow out of the channels, fill an upper plenum chamber and exit through an elbow discharge conduit.

Similarly, when a rotor channel is aligned with the opening to the seawater inlet passageway and the opening to the brine discharge passageway in the lower end cover, the seawater forces the low pressure brine out of the pressure exchanger through the straight discharge conduit [5].

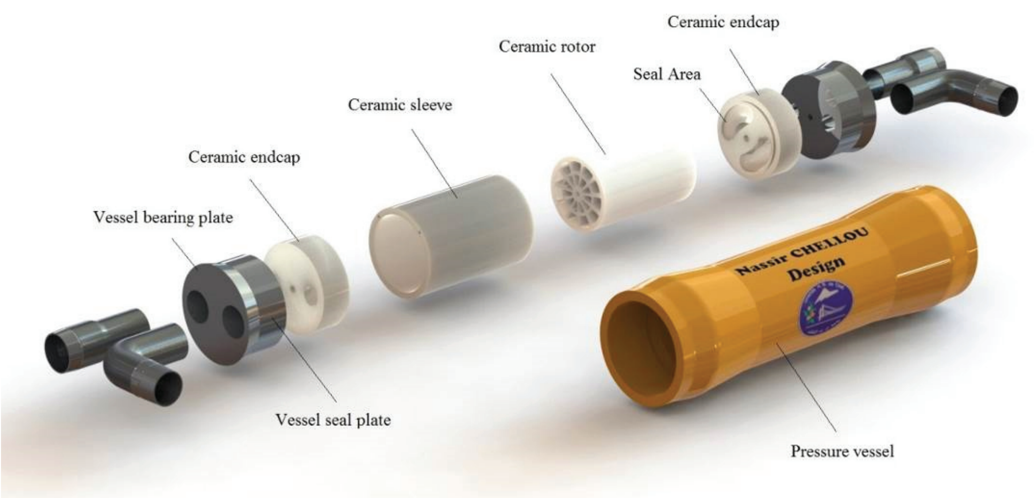

Figure 3 Main components of the Pressure exchanger

3. NUMERICAL SIMULATION

In order to study the efficiency of the pressure exchange in water treatment, a Flow simulation using the CAD/CAE program called Solidworks 2013. The simulation's results are cored from & compared with the ERI SIM V1.3b software data.

The Seawater pressure is injected with a pressure of 2.7 bars (it is mainly injected with 3.4 bars, but once in the filters it get losses during the filtration procedure), the water expulsed from the RO membrane (Brine) is conducted to the curved entry of the PX with a pressure of 63.3 bars (high pressure gained from the pumps used in desalination. Other entries are set as ambient parameters!

For running the Flow simulation in solid works we need to make sure we are done from 2 major parameters; the calculation domain, and the Mesh.

3.1. Mesh

For this study, a mesh of 1 157 497 cells was applied to the fluidic region, in order to have the best refining, & as a result, a better study report will be obtained at the end of the simulation, **Figure 4** shows the Mesh used for the Fluidic volume.

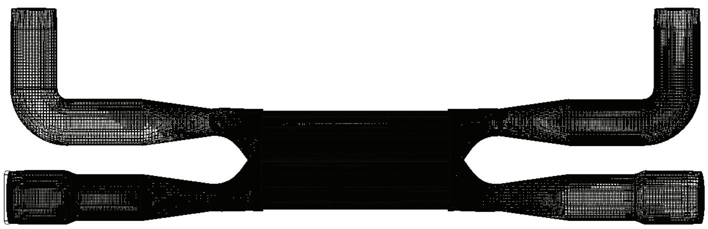

Figure 4 Mesh of the fluidic region inside the PX

3.2. Governing equations

In general the Cartesian mesh approach used in SOLIDWORKS Flow Simulation allows being performed conjugate multiphysics calculations, using one computation mesh having fluid cells, solid cells and (multi-CV) partial cells.

Fluid flow analysis and thermal conduction can also be treated separately. In addition, all these calculations can be coupled with different radiation models. For all these physical phenomena the native CAD geometry remains the source of initial geometric information.

In fluid regions SOLIDWORKS Flow Simulation solves the Navier-Stokes equations, which are formulations of mass, momentum and energy conservation laws [6]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u i)}{\partial x i} = 0 \tag{1}$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) + \frac{\partial P}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\pi_{ij} + {\pi_{ij}}^R\right) + S_i \tag{2}$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial x_i}\left(u_j\left(\tau_{ij} + \tau_{ij}^R\right) + q_i\right) + \frac{\partial p}{\partial t} - \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H \tag{3}$$

Where $H = h + \frac{u^2}{2}$, u is the fluid velocity, ρ is the fluid density, S_i is a mass-distributed external force per unit mass due to a porous media resistance *(S_i^{porous})*, a buoyancy ($S_i^{gravity} = - \rho g_i$, where g_i is the gravitational acceleration component along the *i*-th coordinate direction), and the coordinate system's rotation *($S_i^{rotation}$)*, i.e., ($S_i = S_i^{gravity} + S_i^{porous} + S_i^{rotation}$) h is the thermal enthalpy, Q_H is a heat source or sink per unit volume, τ_{ik} is the viscous shear stress tensor, q_i is the diffusive heat flux. The subscripts are used to denote summation over the three coordinate directions. [7]

The modified ***k-ε*** turbulence model with damping functions proposed by Lam and Bremhorst (1981) describes laminar, turbulent, and transitional flows of homogeneous fluids consisting of the following turbulence conservation laws [8]:

$$\frac{\partial \rho k}{\partial t} + \frac{\partial \rho k u_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right) + \tau_{ij}^{R}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon + \mu_t P_B \qquad (4)$$

$$\frac{\partial \rho k}{\partial t} + \frac{\partial \rho \varepsilon u_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_e}\right)\frac{\partial \varepsilon}{\partial x_i}\right) + C_{\varepsilon 1}\frac{\varepsilon}{k}\left(f_1 \pi_{ij}^{R}\frac{\partial u_i}{\partial x_j} + C_B \mu_t P_B\right) - f_2 C_{\varepsilon 2}\frac{\rho\varepsilon^2}{k} \qquad (5)$$

$$\tau_{ij} = \mu S_{ij}\,,\ \pi_{ij}^{R} = \mu_t S_{ij} - \frac{2}{3}\rho k \delta_{ij}\,,\ S_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k} \qquad (6)$$

$$P = -\frac{g_i}{\sigma_B}\frac{1}{\rho}\frac{\partial \rho}{\partial x_i} \qquad (7)$$

Where C_μ=0.09, $C_{\varepsilon 1}$ = 1.44, $C_{\varepsilon 2}$=1.92, σ_k=1, σ_ε=1.3, σ_B=0.9, C_B=1 if P_B>0, C_B=0 if P_B<0, the turbulent viscosity is determined from:

$$\mu_t = f_\mu . \frac{C_\mu \rho k^2}{\varepsilon} \qquad (8)$$

4. RESULTS & DISCUSSIONS

A virtual desalination plant is designed in the ERI SIM program, build of 14 PX devices & 7 SWRO membranes with a life time of 3 years (as shown in **Figure 5**). With clicking on the button auto start the program start to calculate the properties. What interest us in this study is to see the variation in the pressure during the exchange procedure, a screen shot is taken from ERI SIM program in order to show the main results of the pressure's variation.

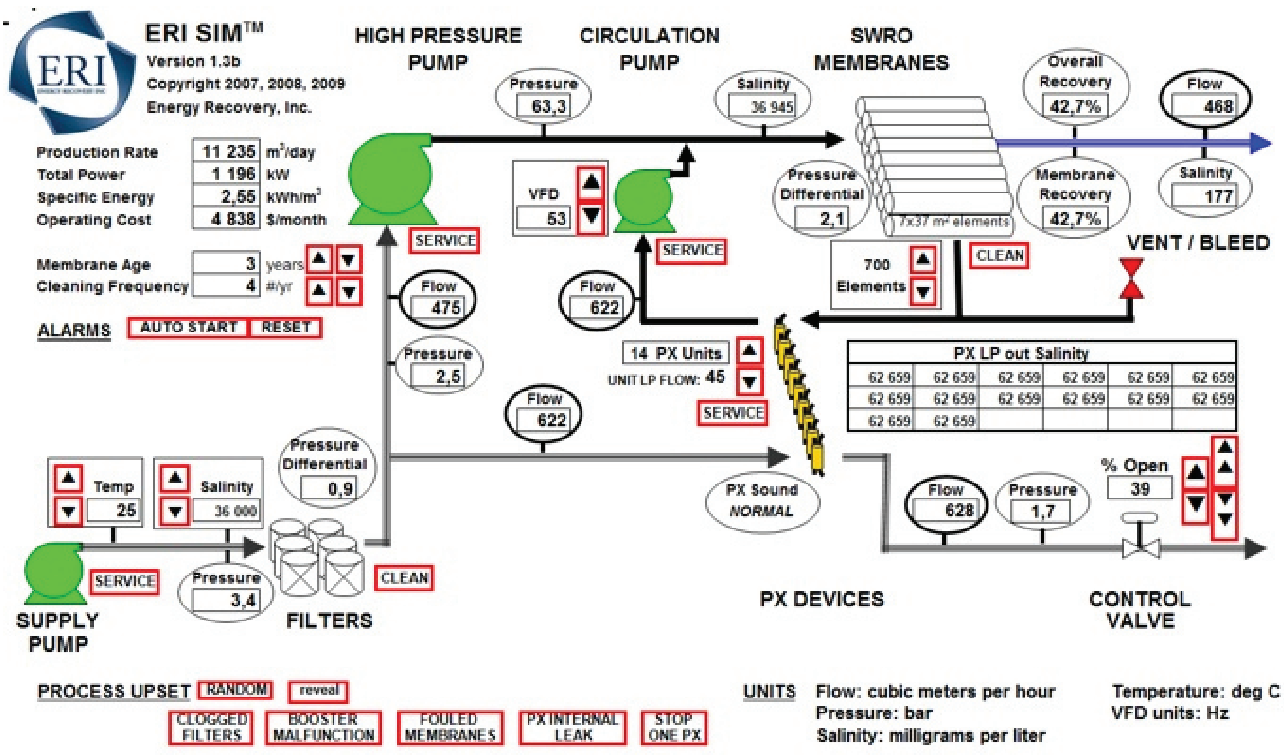

Figure 5 ERI SIM production rate calculation

The results derived from the Flow simulation shows that the seawater after the pressure exchange, gain 52.6 bars from the brine's pressure (63.3 bars). We justify the energy losses due to the circular movement of the ceramic rotor of the PX (1200 tr/min).the brine is again expulsed with a 2.3 bars instead of it was 63.3 bars, where the operation of the pressure exchange appears clearly, same as shown in **Figure 6**.

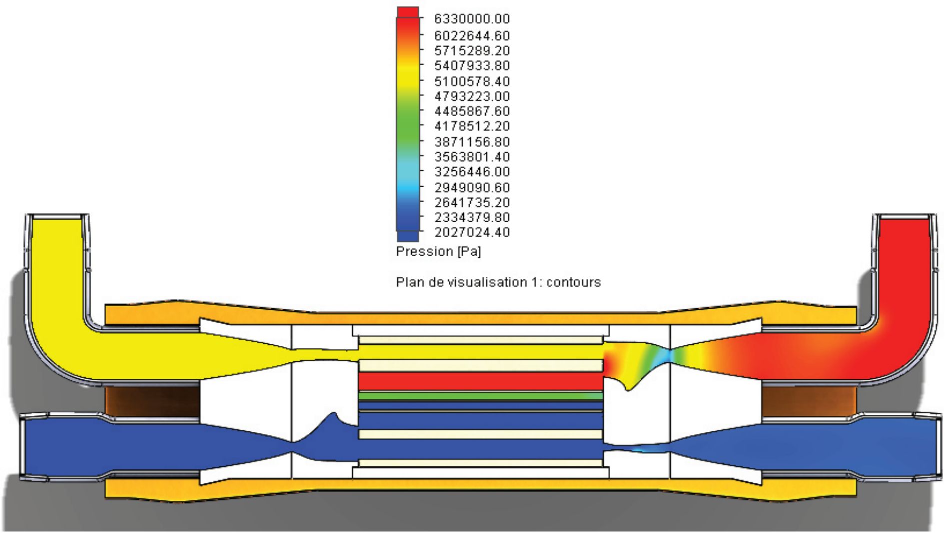

Figure 6 Contours of the pressure in the PX

To verify the Simulation's result with the ERI SIM's values, the option; punctual parameter is up to it in the Flow simulation label in Solidworks. As shown in **Figure 7**, the results are almost similar to the ones of ERI SIM program with mentioning that the same parameters & boundary conditions are used in the flow simulation.

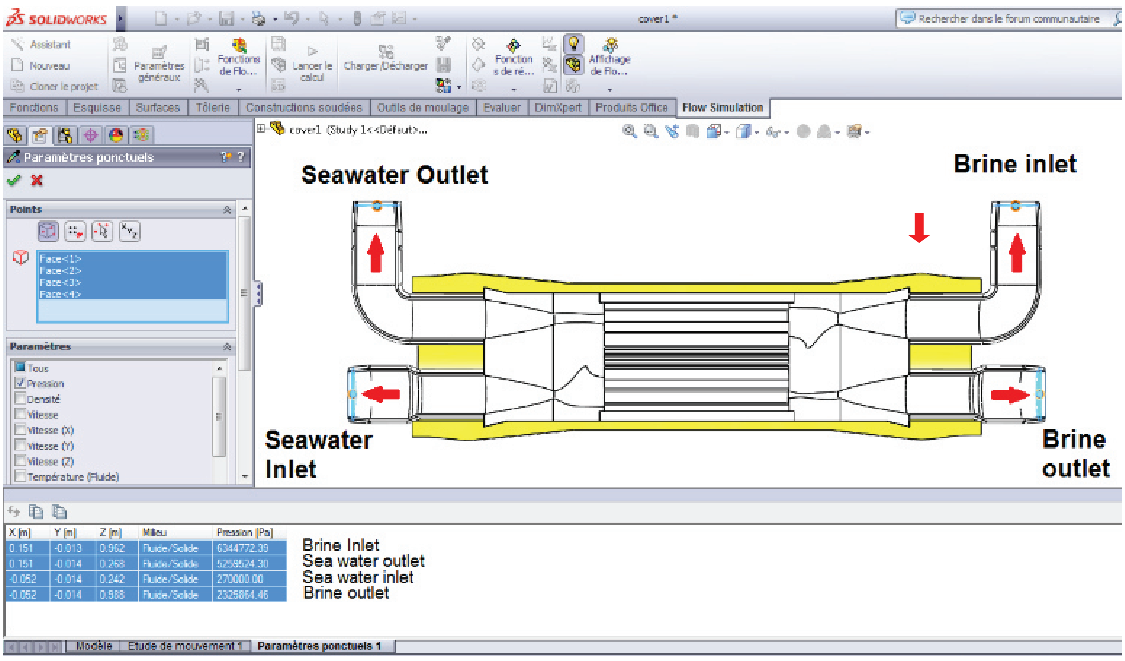

Figure 7 Presentation of the punctual parameters results

When the injected fluid is not a compressible one (water) then the temperature increase slightly but we can consider it as constant. **Figure 8** shows the temperature contours but the aim from presenting them, is to show the liquid piston of water during the exchange procedure.

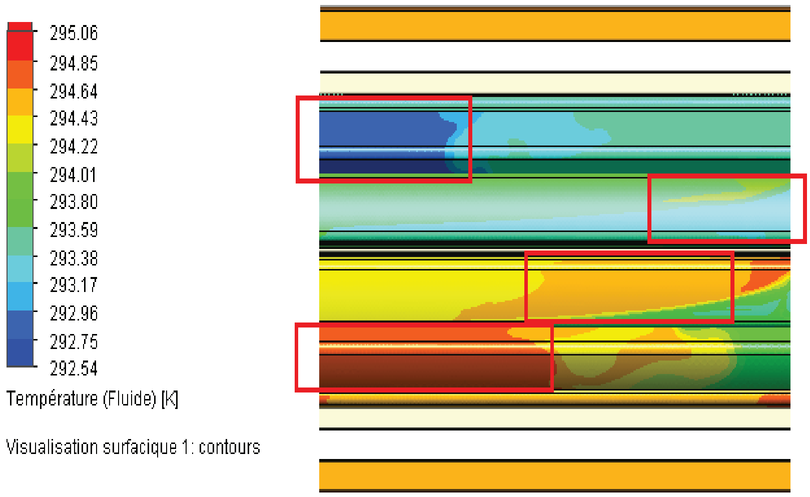

Figure 8 Temperature contours & the liquid piston

5. CONCLUSION

The pressure exchange procedure shows efficiency in providing the sweater with high pressure energy, to be driven with the help of the recirculation pump towards the SWRO membranes, & transform the low seawater pressure to the brine to be expulsed again with a low energy, where a gain of energy of about 60% appears in the reduction of electricity consumption.

The temperature contours shows the formed liquid piston which separate the brine from the seawater, otherwise, the high salinity of brine (62 659 mg/L) will make it inefficient to desalinate water from salt once mixed with seawater.

The Alumina that forms the rotor, sleeve & the end caps (which are the main components of it) makes from the PX a device that resist the massive corrosion of the sweater, & provides a long life time with a 0% maintenance, the matter that justifies the long life time of the PX devices & plants.

In general, we can say that the efficiency of the ERI PX is proven as the best actual device for desalination due to its high performance & energy gain, what derives a less electricity consumption, & in the meanwhile less pollution for the environment.

NOMENCLATURE

Acronyms			
ERI	Energy Recovery Incorporation	PX	Pressure Exchanger
SWRO	Sea Water Reverse Osmosis	RO	Reverse Osmosis
CAD	Computer-aided design	CAE	Computer-aided engineering
SIM	Simulator		

REFERENCES

[1] Energy recovery Inc, A White Paper on High Efficiency Energy Recovery Devices in Desalination Plants, September 2011.

[2] ZHOU Yihui, BI Mingshu and LIU Yu, Rotary Pressure Exchanger for SWRO, Expanding Issues in Desalination, InTech, 2011, School of Chemical Machinery, Dalian University of Technology, China.

[3] R.STOVER, A.ORDONEZ FERNANDEZ, J.GALTES, Permeate Recovery Rate Optimization at the Alicante Spain SWRO Plant, International Desalination Association World Congress: Dubai 2009 - DB09-083.

[4] John P. MACHARG, Stuart A. MCCLELLAN, Pressure Exchanger Helps Reduce Energy Costs in Brackish Water RO System, journa AWWA, Tech Talk pp 44-47, 2004.

[5] Nassir CHELLOU, Study of the Pressure Exchanger's performance and efficiency, Master II Project in Mechanical Engineering, University of Hassiba Benbouali, 2015, Chlef, ALGERIA.

[6] G. DUMNOV, A. SOBACHKIN, 'Numerical Basis of CAD-Embedded CFD' , Dassault system white paper, NAFEMS World Congress 2013, Salzburg, Austria, June ,2013.

[7] Solidworks Flow simulation 2016 Technical refrence, The Navier-Stokes Equations for Laminar and Turbulent Fluid Flows.

[8] Mentor Graphics Corporation, White paper enhanced Turbulence Modeling in FloeFD, 2011.