	Name of the PhD candidate: **Clément LACROIX** Title of the PhD thesis: **Solar-driven thermo-hydraulic process for reverse osmosis desalination** **Dates (start/end):** 10/2016 - 10/2019
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Context and objectives

Access to drinkable water is a major societal issue for remote and isolated areas with high water stress. Existing distillation-based desalination processes are highly thermal energy consuming while membrane desalination techniques are more efficient but they still induce high operating and maintenance costs. Reverse osmosis desalination needs the salty feed water to be pressurized beyond its osmotic pressure (about 30 bars for seawater and 5 bars for brackish water) in order to allow the permeation of pure water through a semi-permeable membrane. The challenge addressed here is to develop a robust desalination processes using solar energy, with the aim of making drinking water accessible to people living in water stressed areas. Solar reverse osmosis (RO) desalination technique, still in emergence, is a promising and sustainable solution with a high potential for innovations and strong economic development by 2030.

Regarding the advantages and drawbacks of both desalination techniques, a new thermo-hydraulic desalination process (Figure 1) is proposed in order to obtain a less energy consuming system with low operating and maintenance costs. It consists of a reverse osmosis process that is directly powered by a Rankine-like engine cycle. This process is driven by low temperature solar heat (70 to 90°C) such the one delivered by commonly used plate solar collectors. The pressurization of the salty water is directly realized in a tank that is connected to the evaporator of the engine cycle: the tank contains a mobile piston, which moves by the expansion of the working fluid of the engine cycle and pressurizes the salty water. This solution enables to reduce importantly the energy conversion losses required for the pressurization of water in conventional RO process and improves the global process efficiency. The pressurized water flows then through a RO module produces clean water and more concentrated brine. A set of two hydraulic cylinders are implemented for recovering the hydraulic energy of the brine flowing out the osmotic unit and making circulate the salty water in the process and the pressurization of working fluid of the cycle between, the low-pressure condenser and the high pressure evaporator. In order to allow a pseudo-continue production, the whole process is composed of two tanks that are operated in phase opposition and alternatively connected to the high-pressure evaporator (to pressurize the tank with gas) and the low-pressure condenser. A hydraulic recovery system composed by two hydraulic cylinders allows the feed water pumping and the working fluid circulation

This new process developed in this thesis targets at the development of an autonomous desalination technology using only solar heat as driving energy source, with a small capacity (<10m^3/day). It implements simple hydraulic and thermal components in order to be cost effective, easy to maintain, and to operate autonomously in off-grid remote areas by using low temperature solar heat provided by common flat plate solar collectors.

This work aims to study the feasibility and evaluate the potential from a technical and economical point of view of such a process for brackish and seawater desalination. The scientific and technological objectives are related to the definition, the optimal design, the definition of the process control and its performance evaluation for various operating conditions, location and solar resource. This work intends to develop an optimization tool according to the daily production targets, amount of produced freshwater and associated energy consumption. Finally, other interesting applications will be evaluated as the treatment of wastewater and polluted effluents by this solar thermo-hydraulic osmotic process.

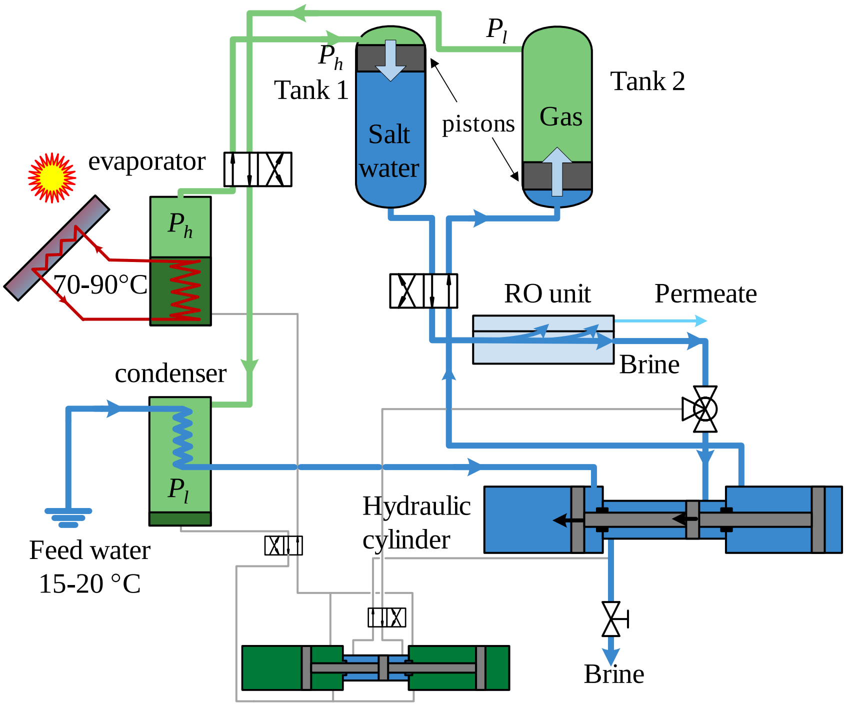

Figure 1: Schematic of the Solar-driven thermo-hydraulic process for brackish water desalination.

Approach

To achieve this goal, a dynamic modeling of the whole process has to be developed in order to assess its highly dynamic behavior, resulting partly from the solar irradiance variation over the day and the engine cycle periodicity (about 2-3 minutes per cycle). This desalination operating mode in such dynamic conditions, that results in high pressure variation imposed on the membrane, has been slightly studied in the scientific literature and simplifying assumptions that can be used has to be analyzed. To achieve this, a dynamic modeling of the behavior of the reverse osmosis membrane, which is key component of the system, is currently carried on in order to implement control strategies for minimizing the impact of transient operating regimes and maximizing the system productivity. An experimental bench has been set up in order to analyze this RO membrane dynamic behavior, and validate the modeling of the reverse osmosis module operating under highly variable pressure conditions.

Main results

The reverse osmosis model has been achieved by considering mass balance equations and membrane transfer equations. A detailed attention has been paid to the calculation of the diffusive layer appearing at the membrane wall, usually calculated in the literature with an established regime assumption. The diffusive layer was thus solved with and without this assumption using a matrix resolution. Simulation results firstly shows that, for low salt concentrations (<10 g/L), highly dynamic working conditions have no critical impacts on the clean water production. Finally, an established diffusive layer assumption doesn't involve important calculation mistakes. This model is currently under experimental validation an adjustment thanks to an experimental bench recently built in the PROMES laboratory. It will be implemented in the global model of the whole solar brackish water desalination process that is also led simultaneously in progress.

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