Library for Dynamic Simulation of Reverse Osmosis Plants

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Abstract: This paper presents a library of simulated components for dynamic simulation of Reverse Osmosis plants. This library has been developed with the objective of testing different control configurations, and fault-detection modules. It consists of a set of simulated components that can be graphically connected to simulate efficiently whole plants. This makes possible to predict quite precisely the evolution of variable of interest for controller design.

1. INTRODUCTION

To combat water scarcity desalination activities are been intensive introduced in arid regions. One of the most popular strategies is the installation of RO desalination plants, which provide a cost-effective and simple solution for desalination (Wilf, 2007).

However, RO are by nature energy intensive, so good control is basic to maintain water-production costs at acceptable level and to elevate the plant availability, particularly in regions with high water scarcity or when removable energy sources are used. Thus, it is crucial to have available dynamic simulation tools so that advanced techniques of control can be tested (Alatiki, 1999; Gambier *et al.*, 2007). It has already been mentioned that the lack of dynamic models and simulation tools limits the application of advanced control in RO plants (Robertson *et al.*, 1996; Gambier and Badreddin, 2004).

Until now, cost reduction and energy saving have been undertaken almost exclusively from the point of view of technological improvement of the basic components of the plant: membranes and pumps (See, for example, Geislera, 2001; Seibert et al., 2004; Stover, 2004). As in many other engineering areas, technological advances in the plant components should be accompanied by a sophisticated control system design, for what adequate simulation tools, such as the one presented in this paper, are needed.

2. REVERSE OSMOSIS PLANTS

The RO process consists in extracting the water from a saline solution by pumping it against a membrane so that it is separated from the solutes (the dissolved material). For this, a differential pressure must be applied, higher than the osmotic pressure of the solution. The water that passes through the membrane (permate) is nearly pure, while the remaining water, with a high salt concentration (brine) is carefully discharged (See Wilf, 2007 for details on the process).

A typical reverse osmosis plant is shown in Figure 3: it can be seen that, apart from the membranes there are many other additional components needed to keep the system running and the water potable. These systems must be included in the simulation in detail, as they affect significantly performance and are the source of many faults in the real plant. From those we emphasize:

- *Pretreatment*, consisting of filtration and addition of chemical products to eliminate microorganisms and prevent precipitation in the membranes.

- *Postreatment*, to potabilize the water produced. This is usually carried out by adding chloride and increasing slightly the salinity, by mixing with filtered salty water.

In the last years, significant advances in membrane technology have allowed an improvement in the filtering quality and simultaneous reduction of costs. Hence, today RO plants demand less energy, investment cost, space requirements and maintenance than other desalination processes (Gambier *et al.*, 2007), so they are been extensively implanted in fresh-water depleted areas, specially combined with clean sources of energy (solar, wind, etc).

3. LIBRARY FOR SIMULATION OF RO PLANTS

3.1. Objectives

The objective was to develop a dynamic simulation of the RO that can be used to:

- decide about design specifications of the different components of the systems, comparing the different alternatives, not only in steady-state but also in transient conditions

- design and tune the control system based on the simulation under different environmental conditions
- design and test the fault detection module, simulating the presence of different faults and malfunctions.

Thus, the first objective was to develop computer models of the different components of the plant that can be used for dynamic simulation of RO plants to test different configurations, and use them to test fault detection and accommodation algorithms. These models have been presented in detail elsewhere (Syafiie, 2008), so this paper presents only the library developed within the EcoSim library.

3.2. *Library components*

The following components typical in a RO plant are included in the library (see Fig. 1 for icons used in the library):

- RO membranes
- Filters (Sand, Cartridges,…):
- Energy Recovery (Isobaric Chambers, Pelton Turbines, etc)
- Pumps (Centrifugal, Positive-displacement, etc)
- Storage tanks, pipes, valves, etc.

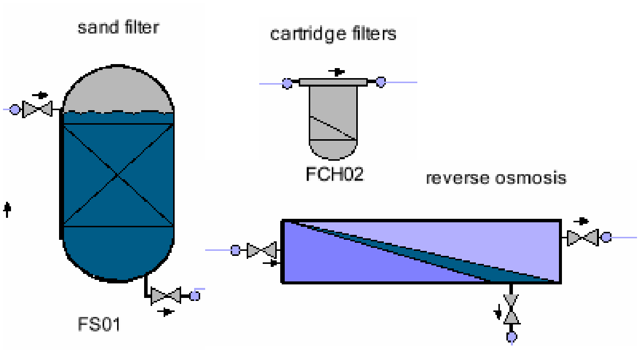

Fig. 1: Graphical representation of different components of the RO Library

3.3. *Input/output variables*

To make possible any interesting interconnection, components in the library are designed to be connected through ports with the following variables:

1) Flow
2) Pressure
3) Salt concentration
4) Concentration of solids, to reproduce faults in filters and membranes.
5) Temperature, to reproduce the effect of water temperature in membrane efficiency (Gambier *et al.*, 2007) and cleaning (Clayton, 1999).
6) An important aspect of RO plant is the power consumption, so pumps and energy recovery systems provide as additional output the power needed to operate, so the library can be used to check different strategies to reduce operation costs.
7) Additional variables are provided for the user to reproduce variables used for process monitoring, such as the Normalized Permeate Flow, Normalized Pressure Drop and Normalized Pressure Passage, used to schedule cleanings and detect critical faults.

3.4. *Methodology*

Modeling was based on using first-principles and empirical models from the literature. These models are then expressed directly using EcoSimPro, as this Simulation Software offers an efficient object-oriented solution to industrial modelling problems, generating directly C++ code that can be used to simulate the RO plant, or interfaced with standard control software.

4. DYNAMIC SIMULATION

There are several simulation tools commercially available, usually provided by membrane manufacturers. However these tools represent only static simulations, so they are very useful for design (sizing, configuration, layout, etc), but they can not be used for testing transient behaviour when

- switching between operational modes (standby/normal operation/membrane cleaning/filter cleaning/shutdown, etc) .
- planning cleaning times
- designing controllers
- designing fault detection algorithms

Compared with this, the developed library can be used for precise dynamic simulation, including starting-up, shutdown and the effect of cleaning and aging. For this, components can be directly connected to simulate whole plants (see an example Figure 3). More important, the dynamic simulations can be easily used to check the responses of the system in different situations: For example, Figure 4 shows the evolution of the permeability of the cartridge filters when a high concentration of fine solids is present in the inlet (typical of surface water): if it were not filtered the filter would clog.

Another example of the possibilities of the library developed is shown in Figure 5, which depicts the evolution of the different flows in a membrane (inlet, permeate and concentrate flows) when the permeate flow is regulated to be kept constant and periodic cleanings are scheduled. From this plot alternative cleaning strategies can be easily evaluated.

5. CONCLUSIONS

This paper has discussed the importance of developing dynamic simulators for designing and operating Reverse Osmosis plants, in terms of optimizing efficiency and designing control software. For this, a library that reproduces the components frequently found in this kind of plants has been presented, showing that it can be used for efficient simulation of RO plants.

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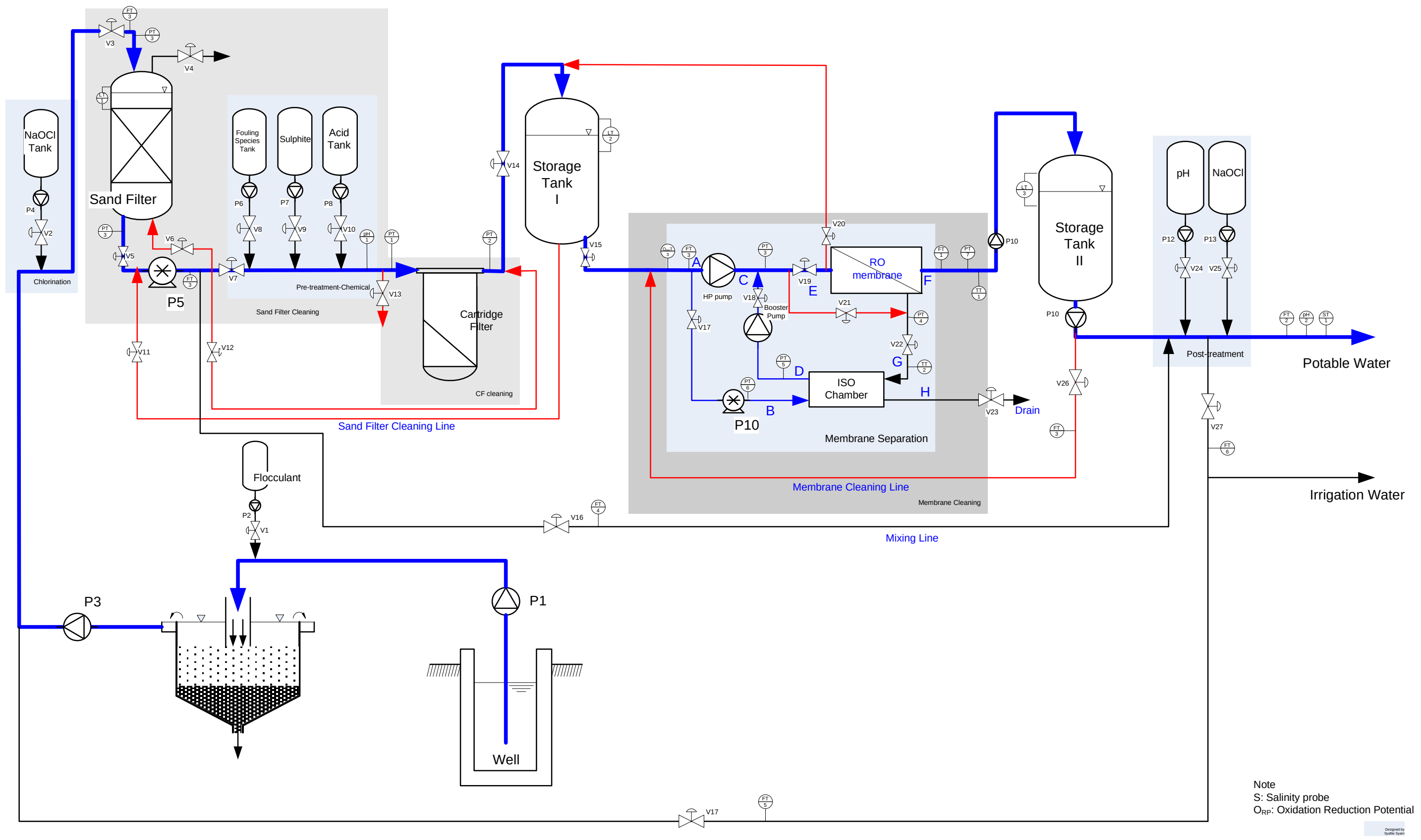

Fig. 2: Layout of a typical RO plant

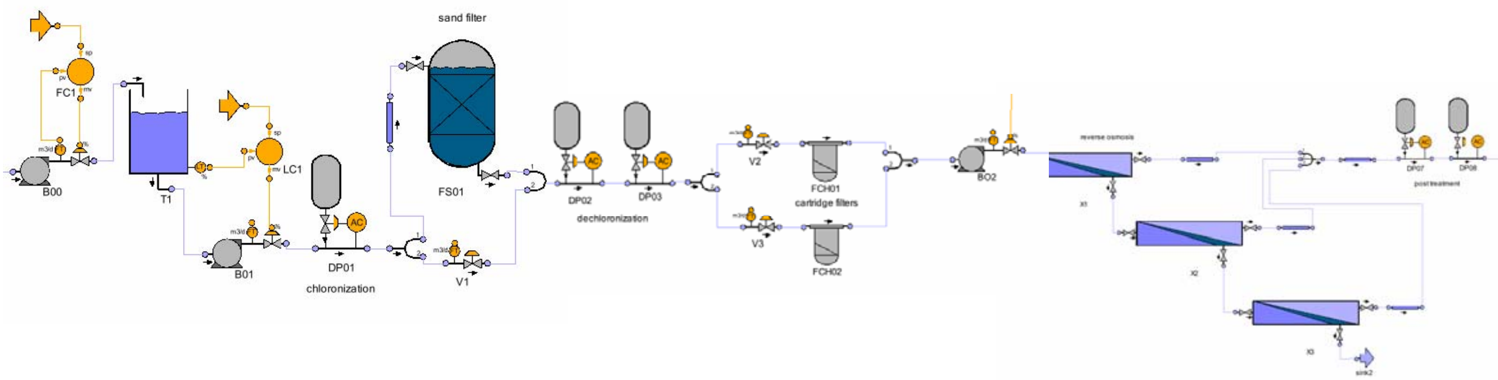

Fig. 3: Graphical simulation of a RO plant

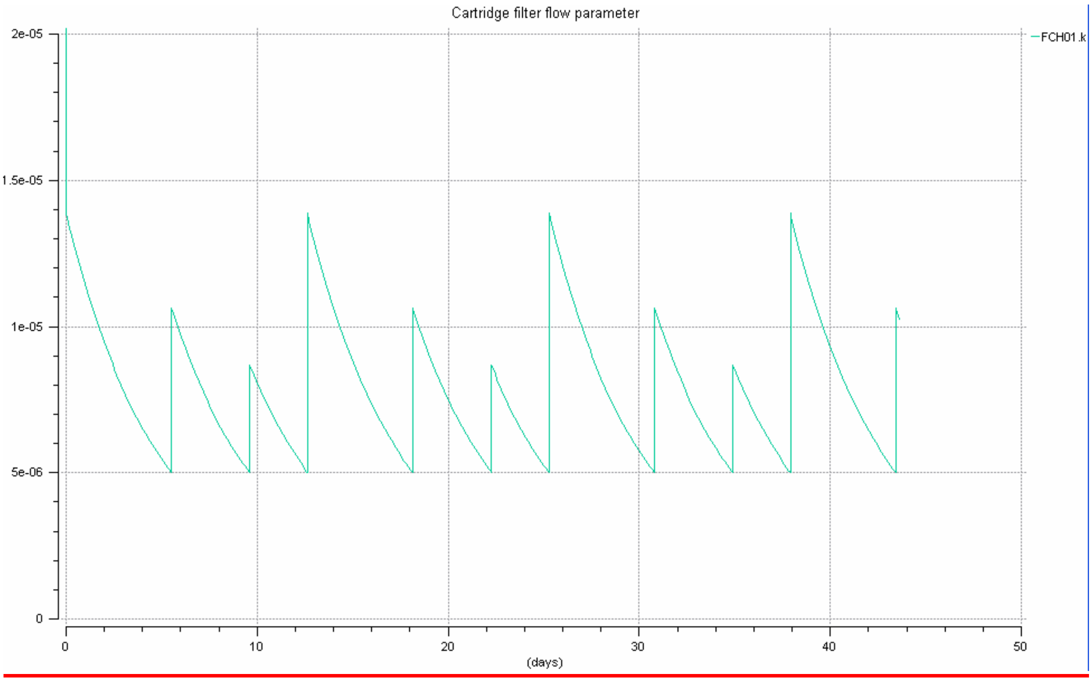

Fig.4: Simulation results for cartridge filter cleaning: permeability evolution with cleanings and replacement for high concentrations of suspended solids.

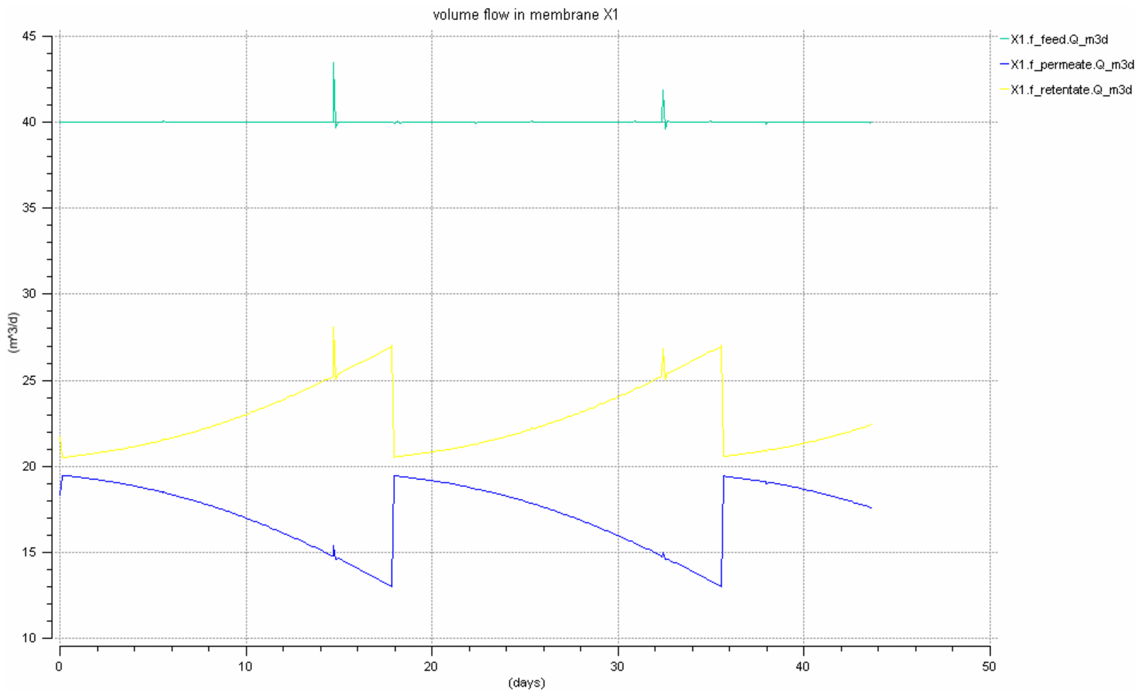

Fig. 5: Simulation results for membrane cleaning: Evolution of flows with cleanings.