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# COMBINING FORWARD AND REVERSE OSMOSIS FOR SHALE GAS WASTEWATER TREATMENT TO MINIMIZE COST AND FRESHWATER CONSUMPTION

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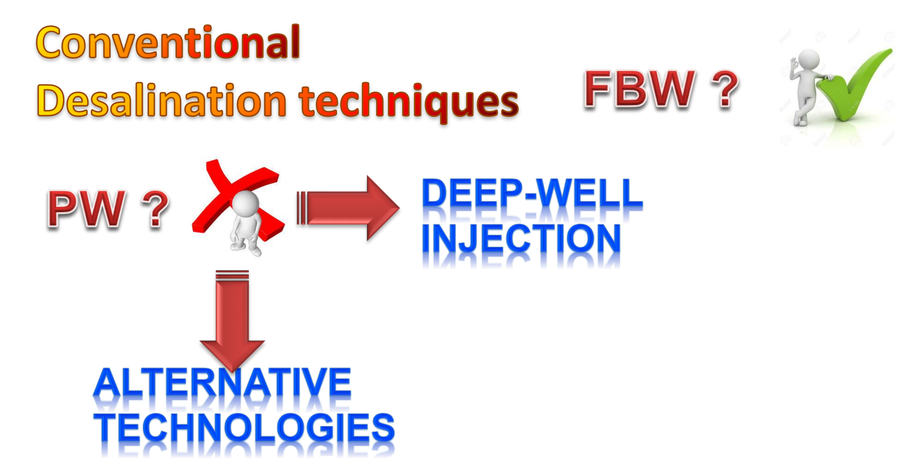
## 1. Introduction

One of the challenges for the future of the **shale gas production industry** is **the water management** due to the large demand of water for wells drilling and fracturing and the high volumes of liquid effluent produced. **On-site treatment** is a convenient option for the reuse of the shale wastewater as drilling water for subsequent wells, which simultaneously **reduces the freshwater consumption and the waste volume**. While conventional desalination technologies are suitable for the treatment of **flowback water (FBW)**, they are not appropriate for the hypersaline **produced water (PW)**, which is typically disposed into underground injection wells.




## Objective

The goal is to design an on-site treatment system, combining FO and RO, which minimizes simultaneously freshwater consumption and fracturing water cost

The reuse of wastewater implies the reduction of the overall liquid waste produced, aiming to achieve ZLD

## 2. Problem statement

The proposed superstructure comprises a **RO** unit, used as **desalination technology**, which product water can replace FW; two FO units; and mixers and splitters allowing all possible connections among the different units (Figure 1). The purpose of the **FO** processes is twofold: they act **as pretreatments for the RO and as waste concentrators**. The feed solutions for FO 1 and FO 2 are the sludge from the FBW pretreatment (also carried out on-site) and the concentrated brine of the RO process, respectively. PW (conveniently pretreated and stored from previous wells, as explained below) is the draw solution for both FO units, where it is diluted before entering the RO process. At FO 1, the sludge from the FBW pretreatment is concentrated since part of its water is transferred to the draw solution, thus reducing its volume and, consequently, its disposal cost. At FO 2, the rejected brine from RO is also concentrated to be transported to an off-site facility where **zero liquid discharge (ZLD)** could be achieved, thereby obtaining more clean water that could be recycled for other uses. The introduction of the PW in the treatment system provides to this water a solution different from being disposed into underground wells.

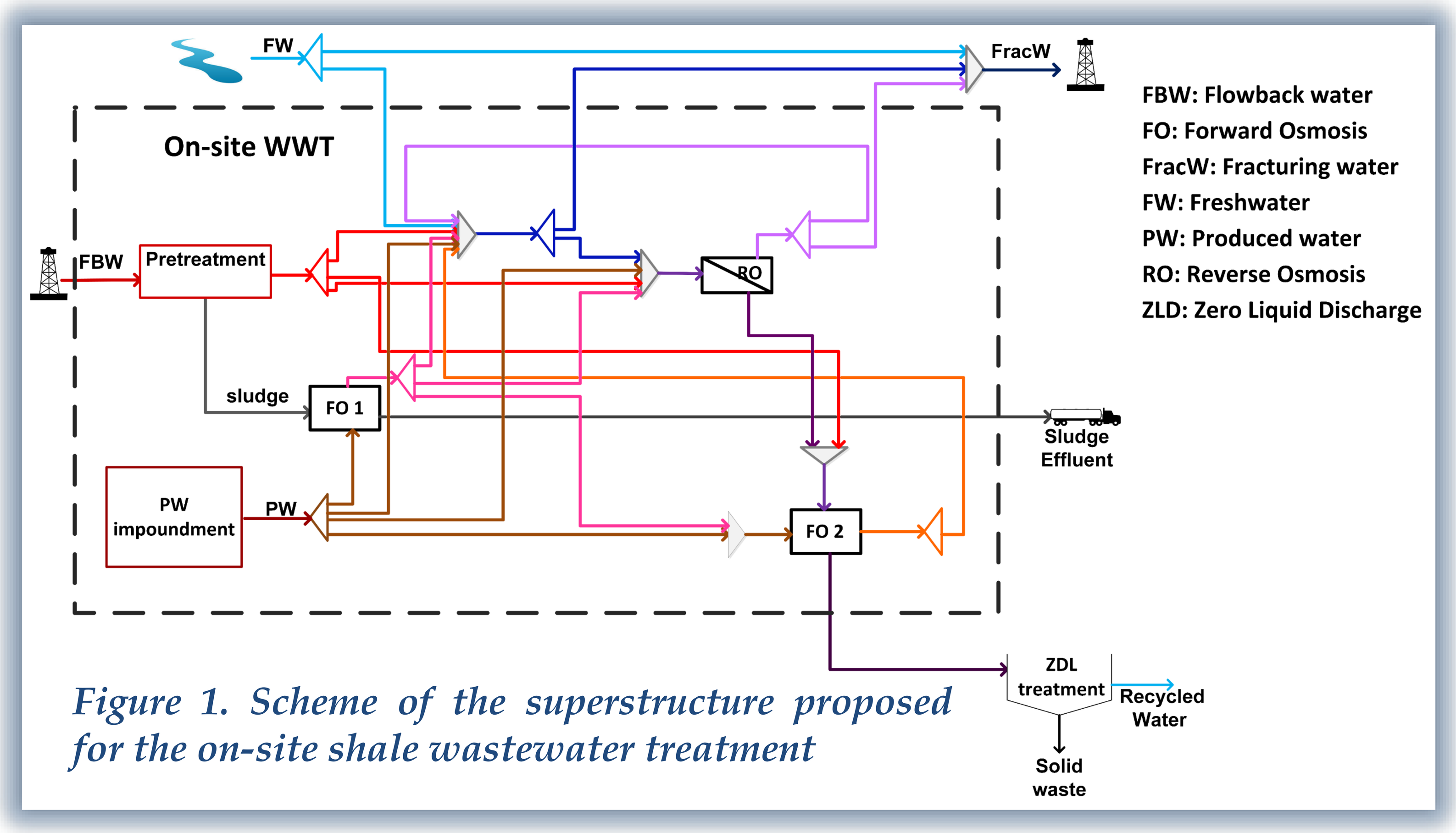



*Figure 1. Scheme of the superstructure proposed for the on-site shale wastewater treatment*

## 3. Mathematical model

The mathematical formulation for the model proposed consists of **mass balances** in mixers, splitters and process units, as well as the corresponding **performance models for RO and FO**, leading to a non-linear programming (NLP) problem, seeking to **minimize** simultaneously the specific total cost, **STC (x)**, and the freshwater consumption, **FWC (x)**.

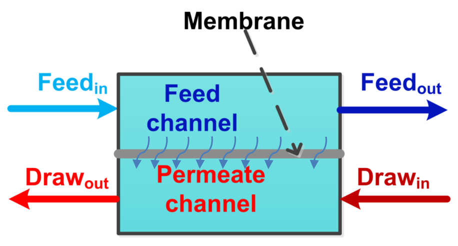
$$\min_{x} \{STC(\mathbf{x}), FWC(\mathbf{x})\} \quad s.t \quad h(\mathbf{x}) = 0, \quad g(\mathbf{x}) \le 0$$

solved by ε-constraint method

$$\min_{x} \{STC(\mathbf{x})\} \quad s.t \quad FWC(\mathbf{x}) \le \varepsilon, \quad \underline{\varepsilon} \le \varepsilon \le \overline{\varepsilon}, \quad h(\mathbf{x}) = 0, \quad g(\mathbf{x}) \le 0$$

**Membrane processes short-cut models**

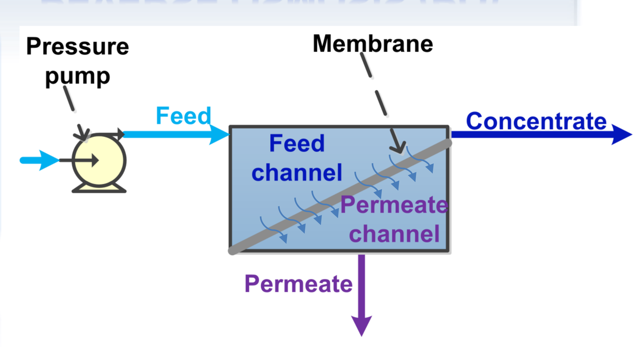
FORWARD OSMOSIS (FO)




$$RO: \; F_p^{RO} = K_m^{RO} A_{memb}^{RO} (\Delta P - \Delta \pi)$$

$$FO: \; F_p^{FO} = K_m^{FO} A_{memb}^{FO} (\pi_d - \pi_f)$$

REVERSE OSMOSIS (RO)




## 4. Results

The solution shows the trade-off between the fracturing water cost and the freshwater consumption and highlights the potential of FO to offer a solution for the problem of PW disposal.

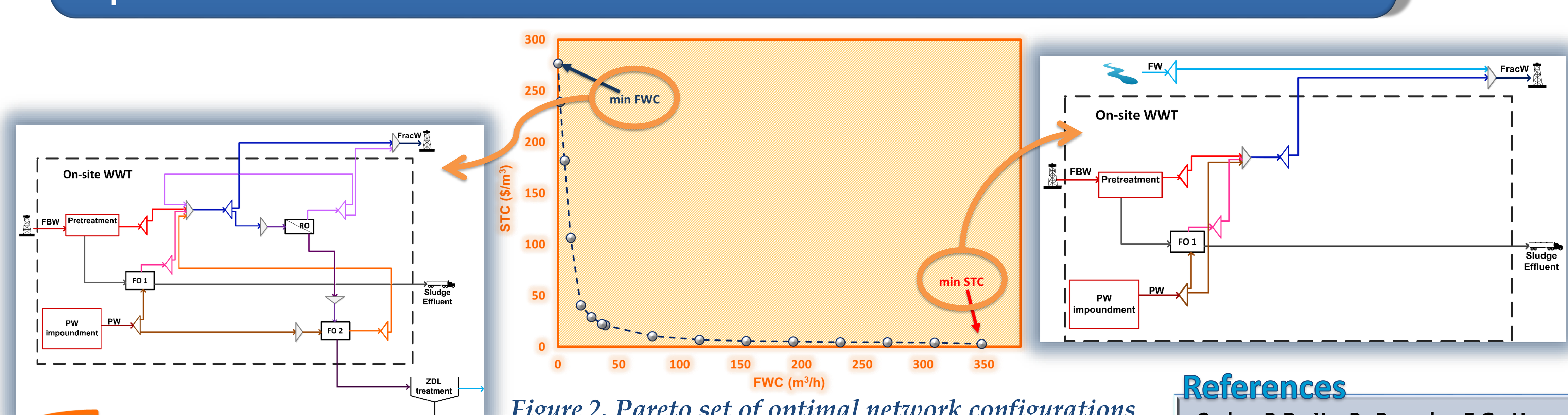



*Figure 2. Pareto set of optimal network configurations*

Freshwater consumption can be avoided but only at the expense of a huge increase in the drilling water cost

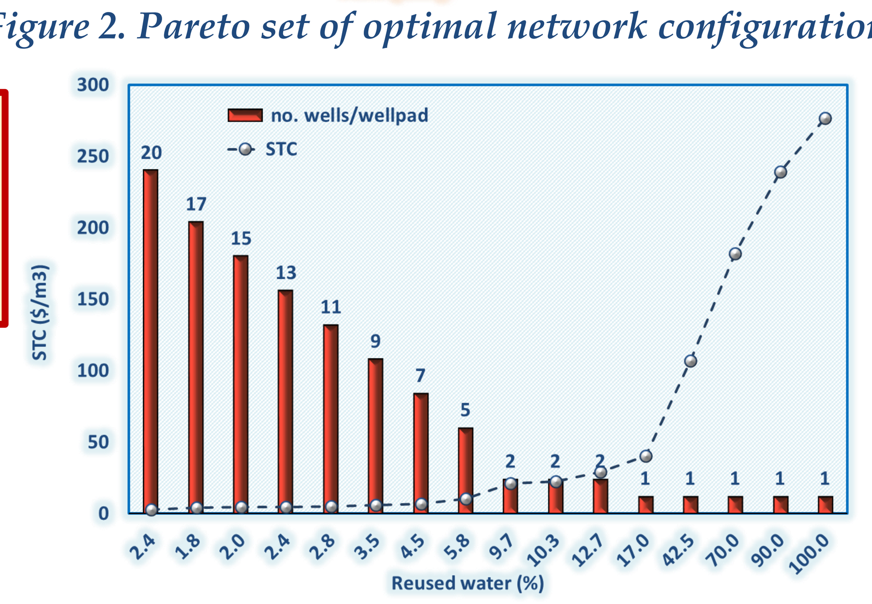



*Figure 3. Reused water proportion, number of wells that can be exploited and STC corresponding to each solution*

## 5. Conclusions

In sight of the results, it is technically possible to use only reused water for the exploitation of new wells. However, the cost of a cubic meter of treated water would be approximately 100 times higher than the same quantity of freshwater. Therefore, an intermediate solution would be a more reasonable option for the design of the proposed system for the attainment of shale gas drilling water.

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