Conférence Internationale en Automatique & Traitement de Signal (ATS-2017)
Proceedings of Engineering and Technology – PET
Vol.23pp.53-56

Reverse Osmosis System Modelled by Pseudo Bond Graph

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***Abstract*—This paper proposes a pseudo bond graph model of reverse osmosis (ROS) system. The reverse osmosis purpose is to filter the water through a semi-permeable membrane which separated the two solutions of different concentrations. In this work, we choose pseudo bond graph to model the ROS for its ability to describe with unified approach all physical phenomenon in the system. The experimental results validate the simulations proposed ROS model by pseudo bond graph.**

***Keywords*—Reverse Osmosis System, Physical Phenomenon, Pseudo Bond Graph, Experimental results.**

I. Introduction

Iindustrial processes are governed by the mutual interaction of several phenomena of various kinds and combine technology components that implement laws from different disciplines. That is why their modeling requires a unified approach. The bond graph [1] tool in multidisciplinary vocation appears best suited to the knowledge of such systems. The dynamic behavior of such systems is usually described by nonlinear differential equations. Their implementation equations by conventional methods and the deduction of state variables is complicated. Their model therefore requires a structured approach can reveal the physical nature and location of the state variables. State variables within the meaning of bond graphs are variables associated with energy storage and directly derived from the model graph.

Finally, process modeling in energy engineering including chemical systems [2], the choice of power variables is not trivial because the number of variables of power is greater than the number of degrees of freedom.

The approach energy bond graphs and use generic variable power to select variables based power system physical model.

This paper is organized as follows: The section 2 is devoted to representation of bond graphs coupled to energy. In section 3 we present the principle of reverse osmosis. Section 4 proposes a new bond graph model of reverse osmosis system and finally discuss and a conclusion is presented. Simulations and experimental results showed in section 4.

II. REPRESENTATION OF BY BOND GRAPH MODEL COUPLED TO ENERGY

A. True and Pseudo Bond graph Model

The mono-energy bond graphs are used for modeling processes involving a single energy at the same time (mechanical, electrical, thermal...). Technological processes in chemical engineering are characterized by the interaction of the thermal, fluid and chemical. These three areas are coupled. The bond graph tool is well suited to such phenomena as the coupling and the influence of different powers (figure 1).

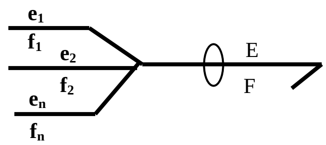

Fig.1: Representation of pseudo bond graphs coupled to energy

In table 1 are represented variables of power and energy Pseudo bond graph used in process engineering [3].

Domain	True bond graph e. f = power		Pseudo bond graph e. f ≠ power	
	Effort e	**Flow f**	**Effort e**	**Flow f**
Electrical	Voltage	Current		
Hydraulic	Pressure	Volumetric flow rate	Pressure	Flow rate mass
Chemical	Potential chemical	Molar flow	Concentrati on	Molar flow
Thermal	Temperature	Entropy flow	Enthalpy specific	Enthalpy flow

Table 1 Generalized pseudo bond graph variables

In electrical and mechanical systems, one area is involved and two physical dual variables are used: voltage-current strength or speed. Thermodynamics three physical domains are involved: thermal, fluid and material or chemical. A flowing fluid, for example is characterized by a set of variables, which is to efforts, the pressure P and temperature T, and for the flow, the volume flow rate (or mass), the entropy flux and flux of momentum. Other variables can also occur such that the heat flow, internal power flow or the enthalpy.

III. REVERSE OSMOSIS SYSTEM

A. *Principle of Reverse Osmosis System*

Osmosis is the transfer of solvent through a membrane under the influence of a concentration gradient [4]. If one considers a system with two compartments separated by a semi-selective and containing two solutions of different concentrations, osmosis results in a flow of water directed from the dilute solution to the concentrated solution. If pressure is applied to the concentrated solution, the amount of water transferred by osmosis will decrease. With enough pressure, the water flow will even cancel: this pressure is called the osmotic pressure P (assuming that the solution is diluted with pure water). If you exceed the value of the osmotic pressure, there is a stream of water directed against the direction of osmotic flow: this is the phenomenon of reverse osmosis in figure 2.

The osmotic pressure of the electrolyte is given by the following relationship

$$\Pi = i.C.R.T \tag{1}$$

This relationship is valid for dilute solutions.
With:

- i : Number of ion species constituting the solute;
- C: Concentration of the solute (mol m-3);
- T: Temperature (K);
- R: Gas constant (8.31 J.mol-1.K-1);
- Π: Osmotic pressure of electrolytes (Pa).

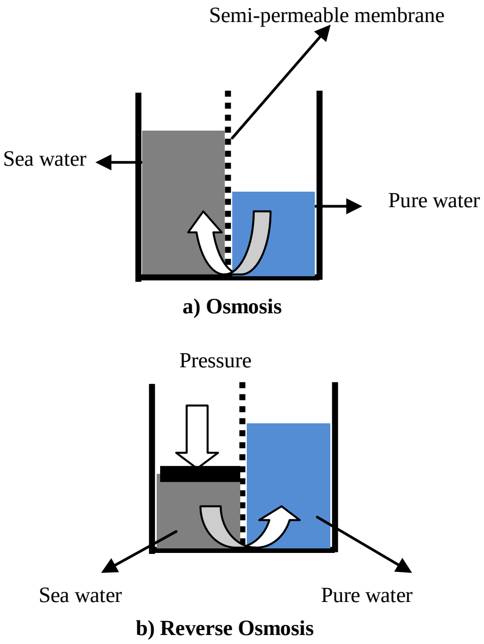

Fig.2.The phenomenon of reverse osmosis

When a solute is dissolved in a solvent, this mixing of the two disordered species produces an increase of the entropy to system and this corresponds to a reduction of the chemical potential (μ_1) [5]. In the case of an ideal solution to reduce the chemical potential is equal to:

$$\mu_1 = \mu_0 + RT \ln a_1 \tag{2}$$

With

- μ_0: Chemical potential of water in the diluted solution (J mol^{-1});
- R: Molar gas constant (R = 8.314 J mol^{-1} K^{-1});
- T: Thermodynamic temperature (K);
- a_1: Activity of the solvent (water) decreases as the solute concentration increases;

At equilibrium, the chemical potential of water in the diluted solution is the same as in the concentrated solution: $\mu_1 = \mu_0$

B. *Transfer mechanisms*

In reverse osmosis, the transfer solvent and solute are by solubilization - diffusion: all molecular species (solute and solvent) dissolve and diffuse through the membrane to the inside thereof, as in a liquid under the action of a concentration gradient and pressure. The transfer longer depends on the size of the particles but their solubility in the middle membrane. Separations are of chemical origin and are related to solvent power of the membrane [6].
The mass flow J_A (kg.m$^{2.}$s^{-1}) of solvent and the volume flow of solvent Q_p (m^{3}s^{-1}) through the membrane are given by the relations:

$$J_A = A.(\Delta P - \Delta \Pi) \tag{3}$$

$$Qp = \frac{AS}{\rho}(\Delta P - \Delta \Pi) \tag{4}$$

Where:

- A: Permeability of the membrane to the solvent (m^{-1}.s);
- S: Surface of the membrane (m^2);
- ρ: Density of the solvent (kg.m^{-3});
- ΔP: Difference pressure side of the membrane (Pa);
- $\Delta \Pi$: Pressure difference osmotic either side of the membrane (Pa).

The mass flow J_B solute (kg.m^{-2}.s^{-1}) of fluid through the membrane is given by the relation:

$$J_B = B(M_0 - M_P) \tag{5}$$

Where

- B: The average permeability of the membrane to the solute (ms^{-1});

- M_0 and M_P: Are respectively the concentration of solute in feed and permeate of either side to the membrane (g.l^{-1}).

IV. BOND GRAPH OF REVERSE OSMOSIS SYSTEM

A. Reverse osmosis system modeled by Bond graph

We propose here a bond graph modeling of reverse system showed in figure 3 and its bond graph model given in figure 4. The most important variables that must be controlled are the permeate conductivity and flow rate [6].

Fig.3. Reverse osmosis system

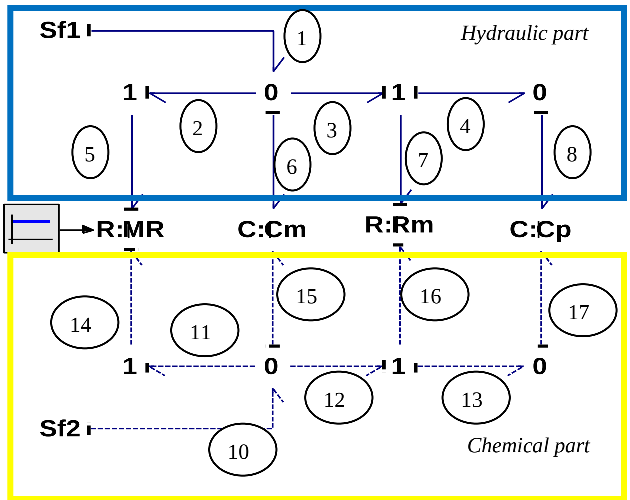

Fig.4. Pseudo bond graph model of reverse osmosis

B. Physical description

The bond graph model of reverse osmosis showed in figure 4 has two parts:

Hydraulic part:

- The solvent inflow (water) of the reverse osmosis (RO) is modeled by a flow source (Sf: Sf_1)
- The RO is equivalent to a storage element and two outputs (produced water and rejected). It will be modeled by pseudo bond graph with a storage element (C: C_m);
- The permeability of the membrane to the solvent is modeled by a restriction element (R:R_m). Its value changes in function of the hydraulic characteristics of the membrane;
- The control valve is modeled by a variable restriction element (R: MR);
- The energy storage of the water produced is described a storage element (C: C_p).

Chemical part:

- The molar flow of solute inflow (water with salt) of RO is modeled by a flow source (Sf: Sf_2);
- The internal energy of the water supply is represented by an energy element (C: Cm);
- The permeability of the membrane to the solute is modeled by a dissipative element (R: R_m);
- The internal energy of the water produced is represented by an energy storage element (C: C_p).

C. Determination of Equations from the Bond Graph Model

Each element of the model is described by two equations, one from the other and hydraulic phenomenon by the chemical phenomenon, for example:

- **Storage element *C: Cm***

From figure 4, one can draw the following equations:

➢ ***Hydraulic part:***

$$e_6 = \frac{1}{C_m}\dot{f}_6 = \frac{1}{C_m}(\dot{f}_1 - (\dot{f}_2 + \dot{f}_3))$$

Or also

$$P_6 = \frac{1}{C_m}\left(\dot{Q}_1 - (\dot{Q}_2 + \dot{Q}_3)\right) \qquad (6)$$

➢ ***Chemical part :***

$$e_{15} = \frac{1}{C_m}\dot{f}_{15} = \frac{1}{C_m}(\dot{f}_{10} - (\dot{f}_{11} + \dot{f}_{12}))$$

Or also

$$M_{15} = \frac{1}{C_m}\left(\dot{n}_{10} - (\dot{n}_{11} + \dot{n}_{12})\right) \qquad (7)$$

- **Restriction element *R: Rm***

➢ ***Hydraulic part:***

$$f_7 = \frac{1}{R_m}e_7 = \frac{1}{R_m}(e_3 - e_4)$$

Or also

$$Q_7 = \frac{1}{R_m} P_7 = \frac{1}{R_m} (P_3 - P_4) \qquad (8)$$

- ***Chemical party:***

$$f_{16} = \frac{1}{R_m} (e_{12} - e_{13})$$

Or also

$$n_{16} = \frac{1}{R_m} (M_{12} - M_{13}) \qquad (9)$$

- P_i: Pressure (Pa);
- Q_i: Flow rate of water (m^3s^{-1});
- M_i: Concentration (gl^{-1});
- ni: Molar flow ($mols^{-1}$).

D. Simulations Reverse Osmosis by Bond graph Model

We used the 20-SIM software to simulate the reverse osmosis system by bond graph model.

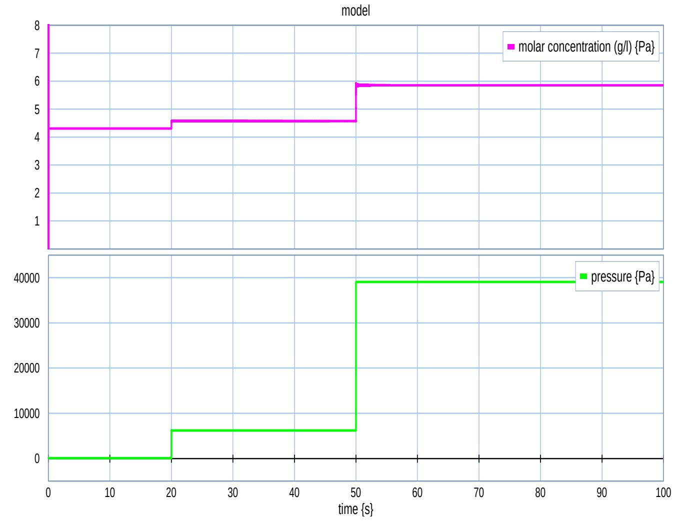

Fig.5. Simulation the evolution to concentration *M* In function of the pressure *P*

It can be seen from figure 5 that the concentration of the pure water increases as a function of the increase in the pump pressure, this being true since when the persistence increases the amount of water which passes through the membrane also increases So the concentration too.

V. Conclusion

Chemical processes are characterized by the interaction of several physical phenomena. Reverse osmosis is among these processes, it has two hydraulic and chemical phenomena. The ininteraction has additional complexity for modeling by analytical approach. The pseudo bond graph is well suited to causal phenomena. Thinks to its structural behavior in this article, we showed how to use a pseudo bond graph approach for modeling and have simulation of a reverse osmosis system.

Future work will focus on the robust diagnostic strategy using bond graph modeling.

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Acknowledgment

We thank the National School of Engineers of Tunis, University of Tunis El Manar to support our work.

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ISSN 2356-5608