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ELECTRIC POWER CONSUMPTION COST MINIMIZATION IN BRINE ELECTROLYSIS BY ION EXCHANGE MEMBRANE REACTORS

IMRE-LUCACI Á.

University "Babeş-Bolyai" of Cluj-Napoca, Faculty of Chemistry and Chemical Engineering, Department of Chemical Engineering, Arany János 11, 3400 Cluj-Napoca, Romania, email: aimre@chem.ubbcluj.ro

ABSTRACT. The brine electrolysis is one of the highest energy consuming industrial electrochemical process, especially electric energy. In many countries are different electric energy costs between day and night to compensate the different consumption demanding in the electric network system. For the brine electrolysis industry it is important to use this situation in its one advantage. There are two main ways to do this:

- by a different current load of the reactors between day/night time period;
- by using a different number of reactors in the day/night time period.

Each variant has positive and negative aspects.

In this paper, based on simulations using a mathematical model of an IEM (Ion Exchange Membrane) reactor, the optimization of a brine electrolysis plant is presented, taking into account both possibilities.

For this purpose, an earlier presented mathematical model of the IEM reactor was further developed to simulate an entire plant. The objective function of the optimization is the minimization of the electric current costs used in the electrochemical reactors and, in the same time, to preserve the level of daily capacity of products (chlorine, caustic soda, and hydrogen).

INTRODUCTION

Energy consumption, especially electric energy, is one of the most important parts of the costs implied in electrolysis processes [1,2].

In the ion exchange membrane process, beside the electrolysers, electric power is used also by the pumps and compressors to pipe the fluids in the process and by the agitators of the vessels and reactors [2].

Minimization of the electric power cost is worthwhile taking into account that the price of the electric energy is depending by the moment of the day (see figure 1). Thus during the day (from 6AM to 10PM) the price is high and during the night (from 10PM to 6AM) is low.

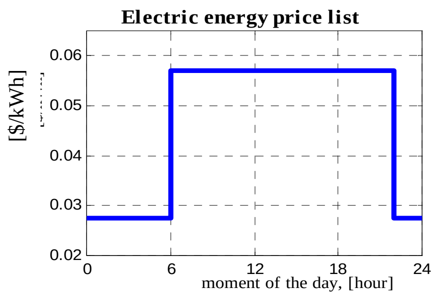

Figure 1. Electric energy price, (Romania, 2001).

To initiate the optimization, in this case to minimize the electric power cost, we need to select the decision variables, to express the objective function and to select and set the constraints.

The optimization is considered taking into account two different approaches:

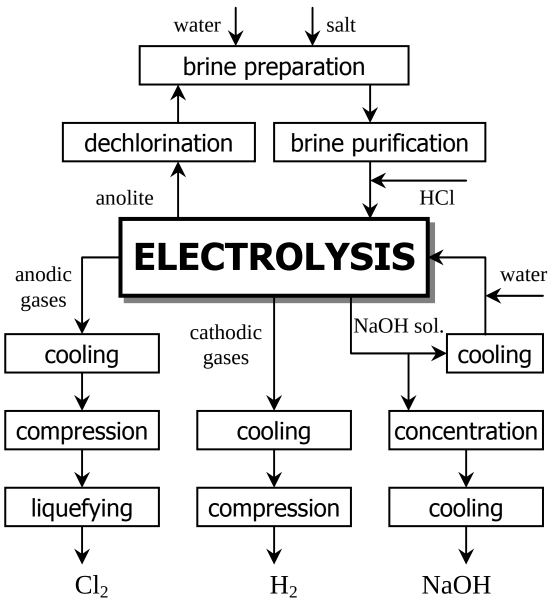

Figure 2. Block diagram of the IEM process.

A. varying the current intensity at which the electrolysers are operated;
B. varying the number of electrolysers operated at a time.

The constraint considered in both cases is an equality constraint in which we fix the production of the plant, expressed in NaOH [t/day].

In both cases we need to express the electric power consumption in the plant depending on the production, current intensity and number of electrolysers. For this, we need to develop a mathematical model of the whole installation in which all fluid streams are included. The block diagram of the entire installation is presented in figure 2. The annual capacity of the plant is 150,000 t of NaOH.

The mathematical model of the electrolyser was presented in previous works [3, 4] and is based on mass, energy and voltage balance equations written for each cell [5-9]. This model includes more than 89 nonlinear algebraic equations. The plant model was developed using ChemCAD process simulation software [10].

This mathematical model was used to show the electric energy consumption taking into account the total current load of the plant and for the second approach, depending on the number of reactor rows in operation at a given time.

The electrical circuit structure for electric energy supply of the electrolysers is a combination of serial and parallel connections, depending by the power supply characteristics. In the case of the considered plant we have the following electrical

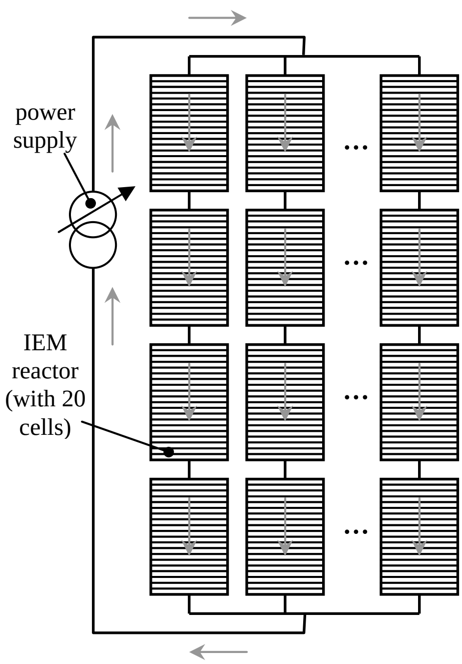

Figure 3. Electric circuit of the plant.

circuits (see figure 3). The power supply can provide electric energy at 240V and 180 KA. For the total capacity we have 80 electrolysers, each with 20 cells, structured in 20 rows (on which electrolysers are coupled in parallel) and with 4 electrolysers in each row (electrolysers coupled in a series).

OPTIMIZATION

To optimize the process, we need to describe through mathematical expressions the costs of electric energy consumed in the entire plant.

For the estimation of the electric energy consumed in the plant (excepting the electric energy consumed in the electrolysers) by pumps, compressors and other electrical operated installations, large sets of simulations in ChemCAD[10] were made. The obtained results were used, by means of regressions, to formulate the dependency expression depending on the capacity at which the whole plant is operated. The estimation of the electric energy consumed in the electrolysis phase was made by simulation based on the mathematical model of the electrolysers. Also, the simulations allow us to compute the voltage at which the electrochemical process takes place.

Case A

In this case the total current intensities at which the plant is operated during the day/night periods were considered as independent variables.

The objective function has the following mathematical expression:

$$\min_{I_{day}, I_{night}} \quad f_{ob} = c_{day}\left(I_{day}\right) p_{day} t_{day} + c_{night}\left(I_{night}\right) p_{night} t_{night} \tag{1}$$

subject to the following constraint:

$$P_{h,day} t_{day} + P_{h,night} t_{night} = P_D \tag{2}$$

Case B

In this second case the numbers of reactor rows operated at a given time in the day/night period were considered independent variables.

The objective function is:

$$\min_{N_{day}, N_{night}} \quad f_{ob} = c_{day}\left(N_{day}\right) p_{day} t_{day} + c_{night}\left(N_{night}\right) p_{night} t_{night} \tag{3}$$

subject to the same constraint (equation 2).

After all these considerations an optimization problem with two independent variables and with an equality constraint was obtained in both cases.

RESULTS

To solve the optimization problems, the Matlab function fmincon from Optimization Toolbox was used.

For case A, the searching domain of the solutions was

$$I_{day}, I_{night} \in \left[0.1\ldots 1\right] \cdot I_{nom} \tag{4}$$

and for case B

$$N_{day}, N_{night} \in [5 \ldots N_{total}] \quad (5)$$

The optimization problem was solved for different values of operating capacities of the plant, starting from 20% of the nominal capacity (150,000 t/year of NaOH) till the nominal capacity. The obtained results were represented in the figures 4 and 5.

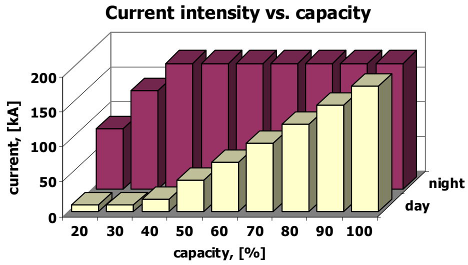

Figure 4. The results of the optimization for case A.

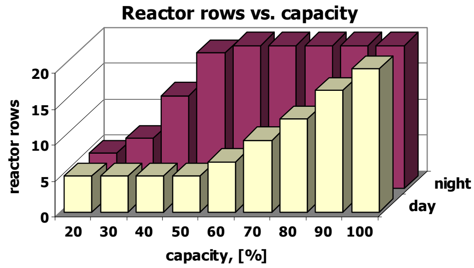

Figure 5. The results of the optimization for case B.

According to these results, the theoretical savings that we could achieve relative to normal operation (without taking into account the differentiated costs of the electric energy) can be observed from figures 6 and 7. The total savings (figure 8 and 9), in [$/year] show us that this problem can have an important economic impact.

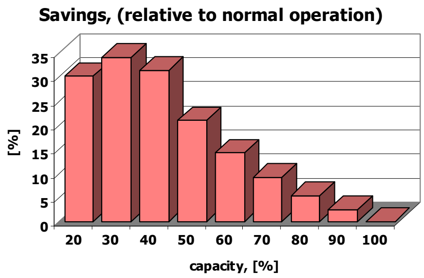

Figure 6. Relative savings in the case A.

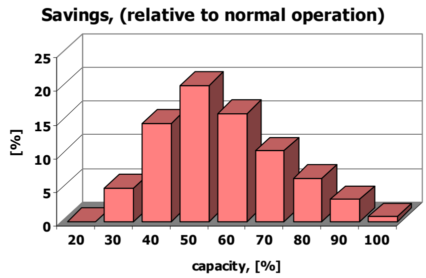

Figure 7. Relative savings in the case B.

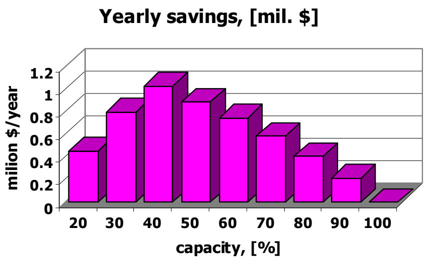

Figure 8. Yearly savings in the case A.

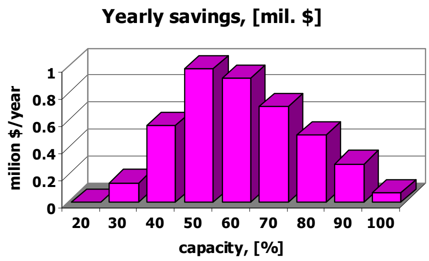

Figure 9. Yearly savings in the case B.

To benefit as much as possible from these economical advantages, we need to have an efficient control system of the electrolysers. This is important in both cases but especially in case A.

CONCLUSIONS

The optimization of an IEM plant was studied in the case of electric energy consumption costs minimization. Taking into account that the price of electric energy is differentiated by the moment of the day, it is possible to use this to obtain important cost savings. The results of the optimization proves that it is possible to obtain 5-20% electric energy cost savings, depending on the relative capacity at which runs the plant at a given moment. Also, the importance of an effective control system is emphasized to preserve the quality of the product during the practical implementation of the optimization results.

NOMENCLATURE

c_{day} plant capacity during the day
c_{night} plant capacity during the night
I_{day} current intensity during the day, [A]
I_{night} current intensity during the night, [A]
I_{nom} nominal current intensity, [A]
$P_{h,day}$ production of NaOH during the day, [t/h]
$P_{h,night}$ production of NaOH during the night, [t/h]
P_D production of NaOH, [t/day]
p_{day} electric energy price during the day, p_{day}=0.058 [$/kWh]
p_{night} electric energy price during the night, p_{night}=0.028 [$/kWh]
N_{day} reactor rows operated during the day
N_{night} reactor rows operated during the night
N_{total} total number of reactor rows, N_{total}=20

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