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Influence of brine spray system on the thermal salt recrystallisation process by dynamic simulation

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Abstract

A distributed dynamic model was built using *gPROMS 2.3.7* language for an integrated Process including a cogeneration system, a plate heat exchangers set and a salt recrystallization process.
It was analyzed the effect of a simulated spray system model on the integrated process, by comparing the global performance of the system with and without sprays. Due to air drift issues, quasi-random time daily profiles for the allowed operation of the spray system (on-off working time periods) were created. Using three distinctive atmospheric scenarios, several ponds spray distributions schemes were analysed. A sensibility analysis of the salt production was considered by changing the brine flow rate fraction entering in the ponds through taps and by sprays.

Keywords: Dynamic modelling, simulation, Process integration, industrial, sprays

1. Introduction

The main goal of this study is to achieve the best operational conditions of an open air industrial integrated system including three processes, by exploiting different atmospheric scenarios, in order to maximize its global energy efficiency and to minimize the environmental impact, reducing the primary energy supply and the raw materials usage. This integrated system, located at Carriço, Pombal (Portugal), includes the following three separated processes: a natural gas salt caverns storage owned by Transgás, a gas turbine cogeneration system owned by Galp Power, and a salt recrystallization process owned by Renoeste. The integration of these three independent units, improves the global system efficiency [1].

2. Dynamic modelling and simulation of the integrated system

The model of the whole integrated process was built through algebraic and differential equations taking into account the phase equilibrium thermodynamics: solid, liquid and gas phases. The integrated system includes the cogeneration system, the five plate heat exchangers and the salt recrystallization process. This involves, mainly, a maximum of six recrystallization ponds, a feed tank and a collecting channel.

The plate heat exchangers (PHE) are the physical connecting set between the cogeneration system and the recrystallization process. The PHE set was included using its design equation and heat balances at both sides.

The pond model considers mass and heat balances axially distributed providing the expected profile inside the ponds (30 elements). The salt saturation concentration depends on brine density and salt solubility values, which vary with brine temperature.

The water evaporation rate is a function of the salt concentration, of the temperature in the brine solution and of the atmospheric conditions (air temperature, humidity and wind velocity). Both for the water evaporation rate and for the convection energy loss it was considered the maximum value obtained between natural and forced convection (mixed laminar-turbulent flow), given the importance of accounting for natural convection, specially at lower wind velocities [2].

The thermal power values (TP) are given by the cogeneration system. The solar energy contribution absorbed through the brine in the recrystallization ponds is the diffuse part and a fraction of the direct solar energy, which is dependent on the brine pond level.

It was included a simplified heated brine spray distribution system model, as an extension of the model previously presented [3], in order to study its effect on the integrated system. It includes its mass balances (water and dissolved salt in the brine solution) and energy balance. The water evaporation rate is a function of the heated brine temperature and is calculated through a linear regression equation based on experimental data obtained at the industrial site [4]. Energy losses were assumed to be 10% of the evaporation energy. Eight sprays are considered in each pond entering through its length, that is, in the axial elements of the pond model (around 30% of the total length).

The whole integrated system was modelled through the general-purpose modelling, simulation and optimization tool gPROMS 2.3.7, of the Process

System Enterprise, Ltd. A flow diagram illustrating the dynamic model structure implemented in this software is shown in Fig. 1. There are five sub-models, including the algebraic and differential equations needed to describe each system. Some variables are used as connecting sub-models information, such as brine flow rate (Q), concentration (X), temperature (T) and density (ρ).

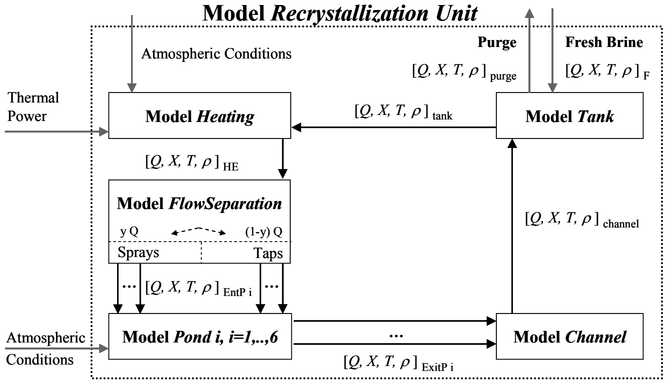

Figure 1. Structure of the dynamic model of the integrated process in gPROMS 2.3.7.

For this model the main state variables are: the number of ponds in service, the atmospheric conditions (wind velocity, air temperature and humidity), the fresh brine flow rate and concentration, the flow rate of the brine pumped into the plate heat exchangers, the TP profile and the solar energy input [3].

3. Influence of the brine spray system

In this paper is analysed the effect of the spray system on the integrated process. Using different operational and atmospheric scenarios, it is compared the global system performance with and without sprays.

Due to brine air drift issues for some wind directions the use of the spray system is prohibitive, and therefore it must be defined on-off spray working time periods. Using atmospheric data obtained from the industrial site, corresponding to 10 months (from August 2005 to May 2006), and by analysing its wind directions values, it was specified the allowed time periods for the spray operation. Then, for each month, it was calculated the mean hourly time percentage of allowed spray use, that is, accounting the number of times that sprays can be turned on in each hour of the day, using all month data. Fig. 2 presents this characteristic day profile of time percentage allowed spray use in each month. Using these mean hourly time percentages it was calculated the total month time mean percentage for the allowed operation of the sprays. Based on theses values, two scenarios were defined: a winter scenario, based on October to January total mean values; and a summer scenario, accounting monthly mean values of February to May, August and September. A third intermediate scenario was also considered.

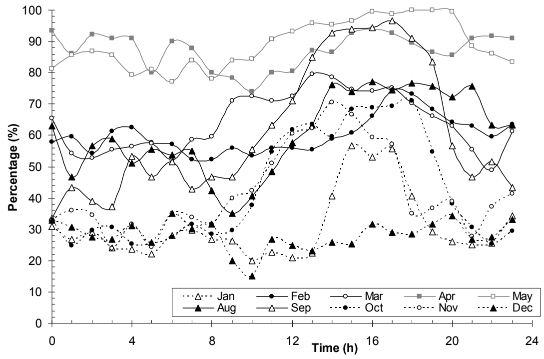

Figure 2. Mean hourly time percentage of allowed spray use in each month.

For each scenario the global time percentage of spray use is constant. It was created a quasi-random time daily profile for the allowed operation of the sprays, which is repeated through the simulation time and respects the fixed global time percentage of spray use defined in each scenario (Table 1).

Table 1. Atmospheric conditions ($T_{air,}$ humidity, wind velocity V, solar energy E), global time percentage and random time daily profile of allowed spray operation, for each scenario.

Scenario	**Winter**	**Intermediate**	**Summer**
Duration (h)	2830	1420	4250
Tair (ºC)	10	17	20
Humidity (%)	75	75	68
V (m/s)	1.3	3.0	2.3
E (kWh/m^2/day)	2.6	4.0	5.5
% Spray use	30%	45%	62%
Daily Profile	1W1S1W1S1W3S	3S1W1S2W3S1W1S	1S1W2S3W2S3W1S
	2W5S1W5S1W2S	3W2S1W2S1W1S2W	4W1S2W1S2W1S

nS = n hours with sprays Stopped (turned off);
mW = m hours with sprays Working.

Table 2 presents the salt production predicted by simulation, when sprays are turned on, using as a comparison to the case base the operation without sprays with 3 ponds in service (100 units of mass per year). The cogeneration system requires the water temperature T_2 within the operational interval of: 90 ± 1ºC. In order to not exceed this it is not possible to work only with two ponds, both with the 8+0 and the 4+4 ponds spray distribution. Furthermore, there is no significant difference between those two operations modes. However, if an 8+8 ponds spray distribution is used, the temperature limit is not exceeded. This case also corresponds to the maximum salt increase, and it should be chosen if it would be possible to invest in 8 sprays for each pond. Otherwise, 3 ponds with an 8+0+0 spray distribution should be used (3.3% of salt increase).

Table 2. Salt production obtained without and with sprays for the considered scenarios (um/year).

Scenario	3P_(0+0+0)	2P_(8+0)	2P_(4+4)	2P_(8+8)	3P_(8+0+0)
Winter	28.7	31.3	31.3	31.9	29.5
Intermediate	16.6	17.4	17.4	17.9	17.1
Summer	54.7	56.2	56.2	57.7	56.7
Total (u.m./year)	100.0	104.9	104.9	107.5	103.3

nP_(v_1+v_2+v_3) = n ponds, with v_1, v_2 and v_3 sprays entering in the first, second and third pond;
■ – Water temperature T_2 is superior to its superior limit (91ºC).

Using the 3P (8+0+0) operation scheme leads to water temperatures values lower than its desirable inferior limit. To avoid this, it was studied the influence of the brine flow rate distribution in the ponds and in the spray system. Consider the following heated brine flow rates:

y Q flow rate entering through the spray system in pond 1;
(1-2 x_{Ti}) (1-y) Q flow rate entering through the taps in pond 1;
x_{Ti} (1-y) Q flow rate entering through the taps in pond 2 or 3;

where y is the flow rate fraction sent to the sprays and x_{Ti} (i=2,3) is the fraction of the flow rate that was not sent to the sprays entering in pond 2 or 3 by taps.
Using as example the summer scenario, and considering the 3P_(8+0+0) operation scheme, it were considered x_{Ti} values from 0.1 to 0.5. The values shown in Table 2 were obtained with x_{Ti} =1/3. Reducing x_{Ti} to 0.1 increases the brine flow rate entering through the taps in the first pond, and decreases it in the two other ponds. When x_{Ti} is increased the opposite occurs, where an x_{Ti} value of 0.5 corresponds to an extreme situation in which the first pond only receives brine when the sprays are turned on, otherwise works as a "solar pond" (Fig. 3).

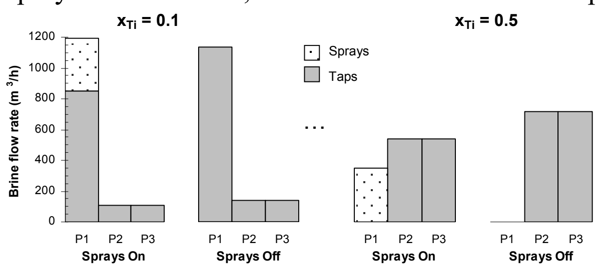

Figure 3. Flow rate distribution in (P_1, P_2, P_3) ponds with sprays on and off, x_{Ti}=0.1 and x_{Ti}=0.5.

Fig. 4 shows the simulation results obtained from the sensibility analysis of the x_{Ti} value, namely, the hot and cold water cogeneration temperatures (T_2 and T_1), heated brine temperature and salt increase when compared to the base operation scheme (no sprays, 3 ponds).
In order to maintain the hot water temperature within the defined operational temperature interval, x_{Ti} should be between 0.15 and 0.2, or between 0.45 and 0.5, corresponding to a salt increase between 4.4 and 4.0%, or between 5.2 and 6.0%, respectively. For the case shown in Table 2 (x_{Ti}=1/3) the salt increase was around 3.6%. Using the smaller values of x_{Ti} means large values of the brine

flow rate in the first pond, while increasing x_{Ti} leads to a higher water temperature oscillation, due to the non constant flow rate entering in the ponds.

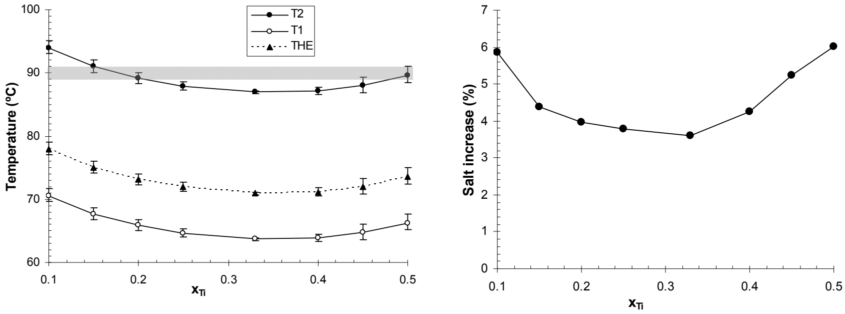

Figure 4. Hot and cold water temperatures (T_2, T_1), heated brine temperature (T_{HE}) and % of salt increase when compared with the base operation (no sprays and 3 ponds), for x_{Ti} from 0.1 to 0.5; ■ – Operational interval for the hot water temperature T_2.

4. Conclusions

It was analyzed the effect of the spray system on the integrated process, by comparing its performance with and without sprays. Due to air drift issues, on-off spray working time periods were defined, by creating quasi-random time daily profiles for the allowed spray operation. Using three characteristic atmospheric scenarios, several ponds spray distributions were analyzed. The best option is to work using two ponds with a (8+8) spray system installed. Due to economical constrains an eight spray system should be used in 3 ponds. For that scheme, in the summer scenario, a heated brine flow rate ponds distribution should be implemented to increase the salt production up to 6%.

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References

1. R. D. Moita, H. A. Matos,C. Fernandes, C. P. Nunes, J. M. Prior, D. A. Santos, In A. Barbosa-Póvoa & H. Matos (eds.), ESCAPE 14 Proceedings, Elsevier, Amsterdam, 2004, 18, 445-450.
2. R. D. Moita, H. A. Matos, C. Fernandes, C. P. Nunes, M. J. Pinho, In A. G. Bruzzone, A. Guasch, M.. Piera & J. Rozenblit (eds.), EMSS 2006 Proceedings, Barcelona, 2006, 441-450.
3. R. D. Moita,. H. A. Matos, C. Fernandes, C. P. Nunes, J. M. Prior, Computers and Chemical Engineering, 29 (2005) 1491.
4. J. M. Prior and F. Rocha, Industrial Internal Report, Carriço, Portugal, 2005.