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Heat recovery in milk powder drying by using a liquid sorption process

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Abstract

The last step in the production of milk powder is drying, an energy intensive process that demands 30% to 40% of the total energy input of a typical plant. It takes place in Spray Dryers (SD), where concentrated milk is sprayed and placed in direct contact with hot and dry air that cools down and gains humidity as water is evaporated from milk. The warm and humid air leaving the SD contains a small portion of potentially recoverable sensible heat and a large portion of latent heat that is impractical to recover by direct condensation due to the low dew point of this stream and due to the presence of milk powder particles that become sticky at high relative humidity values. In this research, the thermodynamic feasibility of a liquid sorption system for the recovery of heat from the exhaust of SD's was investigated. The system proposed has two main advantages: the dehumidification of air in the absorber for reuse in the SD, and the production of medium pressure steam in the regenerator for integration to the steam network of the plant. A mathematical model was implemented in Matlab, and two system configurations were evaluated. The calculations showed that a SD equipped with this system can achieve energy savings between 58% and 99% when using aqueous solutions of phosphoric acid as liquid desiccant depending on the system configuration. The challenge with this liquid desiccant remains on the construction materials.

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Keywords: milk powder spray drying; liquid sorption; heat recovery; energy efficiency; liquid sorption heat pump; air dehumidification; liquid desiccants

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Nomenclature

ES	Energy savings, [%]
h	Specific enthalpy, [Jkg^{-1}]
$\dot{m}$	Mass flow, [kgs^{-1}]
P	Pressure, [kPa]
$\dot{Q}$	Heat transfer rate, [W]
T	Absolute temperature, [K]

Greek letters

ξ	Mass fraction of solute, [$kg_{slte}kg_{sltn}^{-1}$]
ω	Abs. humidity of humid air, [$kg_{water}kg_{da}^{-1}$]

Subscripts

a	Humid air
abs	Absorber
j	Position in a column
da	Dry air
reg	Regeneration
ref	Reference
SHX	Solution Heat Exchanger
slte	Solute (anhydrous desiccant)
sltn	Liquid desiccant solution
ss	Strong solution
ws	Weak solution
v	Vapor
VHX	Steam condenser

Superscripts

G	Gas phase
L	Liquid phase
sat	Saturation
v	Vapor (refer to vapor pressure)

1. Introduction

Drying is an energy intensive process that accounts for 10 – 20 % of the total energy used in industry in developed countries [6]. It is the last step in the production of many products in several industrial sectors including food and beverage, pharmaceutical, paper, petrochemical, among others. The large energy consumption of drying processes is due to the large heat of evaporation needed to remove water or other solvents from the solid. A reduction of the energy consumption of drying processes would contribute substantially to reduce the use of fossil fuels and the greenhouse gas emissions in industry.

The drying process of milk powder is a convective-drying process that commonly takes place in Spray Dryers (SD). In a conventional milk powder SD, air enters at temperatures between 180 °C to 200 ° C and with an absolute humidity between 4 to 8 $g_{water}/kg_{dry\ air}$. Concentrated milk enters the SD with 50 % solids content and at approximately the wet bulb temperature of the entering air. Special nozzles spray the concentrated milk inside the SD, and the milk droplets get into direct contact with the hot, dry air. Water is evaporated from the milk droplets and swept away in the air stream. Air leaves the SD at temperatures between 70 °C to 80 °C and humidity content between 45 to 50 $g_{water}/kg_{dry\ air}$. A conventional SD for the production of 3000 kg/h of milk powder, dry basis, uses approximately 3.3 MW for heating about 20 kg/s of ambient air from 20 ºC to 180 ºC. Two thirds of this energy flow are actually used for the vaporization of water from milk, i.e., converted into latent heat, and the rest remain as sensible heat.

The simplest method for the recovery of energy in milk powder SD's is to implement an exhaust-to-inlet-air heat recovery system, which offers energy savings of the order of 15 to 20 % in comparison with the energy consumption of a SD without heat recovery [9]. The effectiveness of cross-flow, air-to-air heat exchangers, which according to Golman and Julklang (2014) [5] ranges between 50 to 70 %, limits the energy savings achievable by this method. Furthermore, even after filtering, the exhaust air contains a small fraction of milk powder particles, which may become sticky and pollute the heat exchanger if the relative humidity increases above a certain limit as the exhaust air is cooled down [1]. As a result, the temperature of exhaust air must remain above approximately 50 °C, which also limits the energy savings achievable by this method. On the other hand, the recovery of latent heat from the exhaust air by direct condensation is impractical because of the low dew point of this air stream and because of the stickiness of milk powder particles.

The sorption methods emerge as an alternative for the recovery of heat from the exhaust of milk powder SD's. Researchers of the Wageningen University and TNO, The Netherlands, have proposed the use of the zeolite-wheel technology for the recovery of heat from the exhaust of SD's [10]. Calculations indicate that this system offers energy savings between 45 to 55 % of the energy consumption of a conventional SD. However, this technology still needs to overcome some challenges related to the large heat of regeneration of the zeolite, a part of which is difficult to recover, and the risk of pollution of the zeolite material with milk powder particles present in the exhaust air.

An alternative to the zeolite-wheel system is the liquid sorption technology, which is evaluated in this study. The name given in this paper to the liquid sorption system for the recovery of heat in milk powder SD's is 'EELS', which stands for 'Energy Efficient drying by using Liquid Sorption'. The EELS system consists of an absorber, a regenerator, and a solution heat exchanger added to a conventional SD. A liquid desiccant absorbs

water vapor from the exhaust air in the absorber yielding hot and dry air for reuse in the SD if a closed configuration is used or for preheating the inlet air of the SD in the case of an open configuration. The regenerator requires high-temperature heat for the regeneration of the liquid desiccant and yields medium-pressure steam. The use of this steam in other heating processes of the plant represents the energy savings of the EELS system. This study evaluates the feasibility of the EELS system from a thermodynamic standpoint. This paper will present a description of two configurations of the EELS system and a description of a mathematical model built for the evaluation of the thermodynamic limits of these configurations.

2. Description of the EELS system

The EELS system is a liquid sorption system that can be installed as an add-on to existing milk powder SD's. Two basic configurations of the EELS system will be considered in this paper: a closed configuration on the air side, and an open configuration on the air side, which will be described in what follows. A review of liquid desiccants for the EELS system is also presented at the end of this section.

2.1. Closed configuration of the EELS system

Fig. 1 shows a basic scheme of the closed configuration of the EELS system, in which air is completely recirculated to the SD after passing a non-adiabatic absorber. Ideally, the absorber yields dry, hot air at 180 °C and 8 $g_{water}/kg_{dry\ air}$, the conditions required for the SD. The liquid desiccant solution enters at the top of the absorber with a temperature of about 185 °C and with a vapor pressure of approximately 1 kPa and leaves at the bottom with a temperature of approximately 107 °C and a vapor pressure of about 6 kPa. Part of the heat of absorption is transferred to the air stream, and the rest is removed from the absorber by an external cooling medium. On the other hand, the regenerator yields medium-pressure steam at the top and a concentrated solution at high temperature at the bottom. The steam produced in the regenerator is a standard commodity useful for several heating processes in the plant. The solution heat exchanger, SHX in Fig. 1, reduces the heat of regeneration by preheating the weak solution with the hot concentrated solution. The regeneration of the liquid desiccant requires a high-temperature heat flow that is comparable in quantity to the heat input of a conventional SD. The advantage of the EELS system is that the heat of regeneration is almost completely recoverable. This is because the temperature of the steam produced in the regenerator and the final temperature of the fluid used for cooling the absorber are high enough for several heating applications in the plant.

2.2. Open configuration of the EELS system

Fig. 2 shows a scheme of an open configuration of the EELS system, which uses an adiabatic absorber for the dehumidification of the exhaust air. It also uses an exhaust-to-inlet-air heat exchanger for recovering sensible heat from the partially dehumidified exhaust air. This configuration has two main advantages. First, the simplicity of the adiabatic absorber, which also represents a lower cost. Second, air is not recirculated to the SD after passing the absorber, which eliminates the risk of contamination of milk powder with traces of liquid desiccant. The regenerator of this configuration works like the regenerator of the closed configuration. A disadvantage of this configuration is that the energy savings are lower because the exhaust air vented still contains some sensible and latent heat.

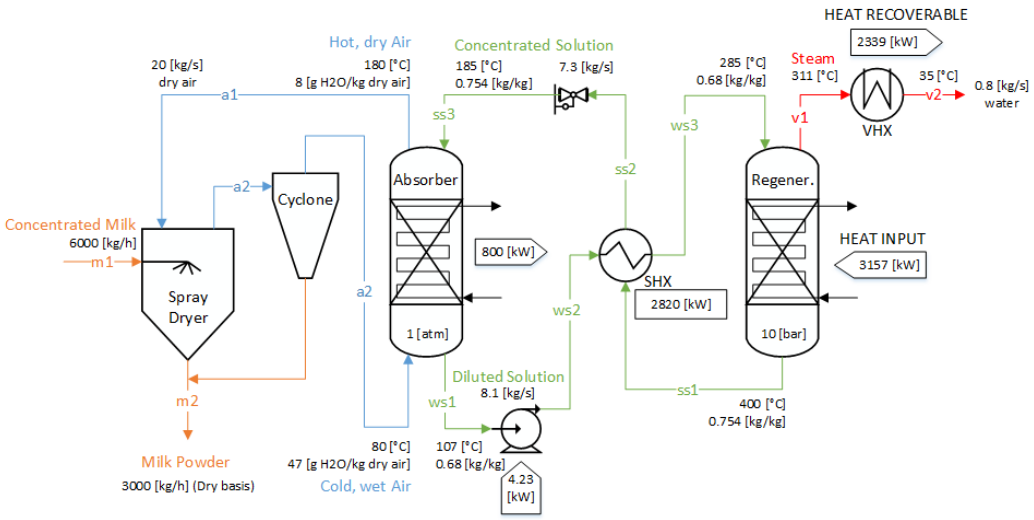


Fig. 1. Closed configuration of the EELS system integrated to a SD.

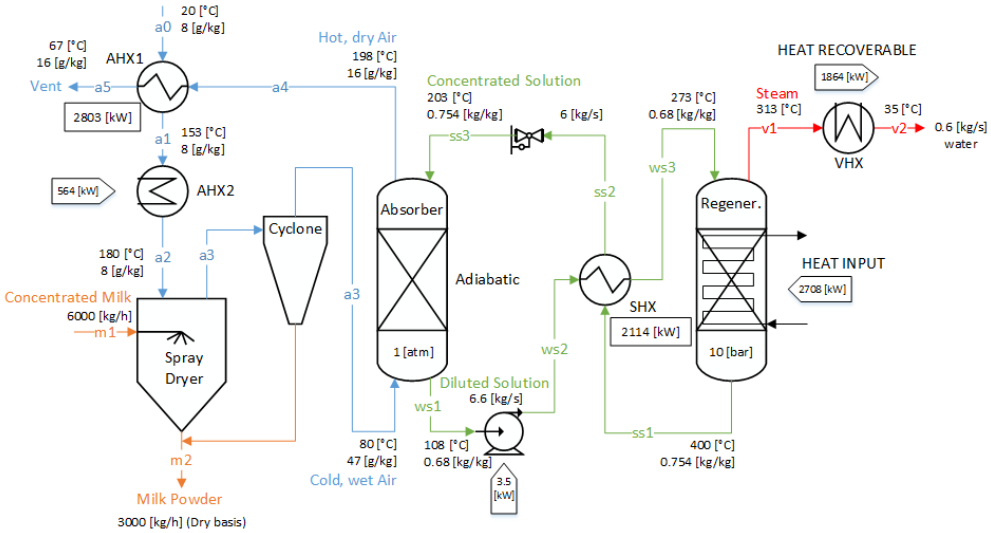


Fig. 2. Open configuration of the EELS system using an adiabatic absorber and an exhaust-to-inlet-air heat exchanger to recover sensible heat of the partially dehumidified exhaust air before it is vented.

2.3. Liquid desiccants for the EELS system

The ideal liquid desiccant for the EELS system should have the following characteristics:

- It must be able to attain a temperature over 180 °C for a vapor pressure of 1 kPa. This is in order to allow dehumidifying and heating the exhaust air to the required levels for reuse in the SD.
- It must have very low or zero volatility at the conditions of the absorber and regenerator.
- It must have a high absorption capacity.

From a more practical perspective, some additional characteristics of the liquid desiccant are desirable:

- It must have low corrosiveness, or suitable construction material should be available.
- It must be non-flammable and non-toxic.

A review of the properties of several liquid desiccants commonly used in 'liquid desiccant-based air conditioning systems' led to the conclusion that these liquid desiccants are not suitable for the EELS system. Liquid desiccants like aqueous solutions of Lithium Chloride (LiCl), Calcium Chloride ($CaCl_2$), Lithium Bromide (LiBr), Calcium Nitrate ($Ca(NO_3)_2$) were considered. It was found that these solutions are unable to

reach temperatures above 180 ºC for a vapor pressure of 1 kPa [3], [8], [11], condition that is necessary in order to dehumidify and heat up the exhaust air to the required levels for the SD.

On the other hand, it was found that aqueous solutions of phosphoric acid can reach temperatures over 180 °C for a vapor pressure of 1 kPa. These solutions have also negligible volatility of phosphate species for concentrations below 76 wt% P_2O_5 [3]. Phosphoric acid is a very corrosive fluid, but it was decided to ignore this fact in this study in order to validate the EELS concept. Therefore, it was selected as the working fluid for the EELS system. The results of the calculations presented in this paper correspond to the use of aqueous solutions of phosphoric acid as the liquid desiccant of the EELS system.

3. Mathematical model

A steady-state model of the different components of the EELS system was developed and implemented in Matlab in order to determine heat and mass flows, and the state of the liquid desiccant solution and the air stream at different locations of the system. The model yields the energy flows required for the calculation of the percentage of energy savings of both configurations of the EELS system. The subscripts of the variables in the equations presented below coincide with the tags of the air and desiccant streams in Fig. 1 and Fig. 2.

3.1. Absorber

The main assumptions of the model of the absorber are:

- The absorber is divided into stages.
- Equilibrium is achieved between the liquid desiccant and the air stream leaving every stage. This means that humid air and the liquid desiccant have the same temperature and vapor pressure at the leaving ports of every stage.
- The absorption of other substances (i.e. CO_2, O_2, N_2) is neglected.
- The entrainment of desiccant in the air stream is neglected.
- The desiccant is not volatile.
- Plug flow (i.e. no mixing of desiccant or air in the absorber)

The equilibrium-based model of the absorber is based on the MESH equations (Mass balance, Equilibrium, Summation, and Heat balance). In this case, due to the assumptions indicated above, the summation equations can be merged to the mass balance equation so that for every stage of the absorber only three equations are attainable. Equations (1), (2), and (3) present the mass balance, the vapor pressure equilibrium, and the heat balance for an equilibrium stage. It is relevant to mention that these equations are written in the form $f(\boldsymbol{x}) = 0$, which is convenient for the application of the Newton Raphson numerical method for the solution of the system of equations.

$$M_{H_2O,j} = \frac{\dot{m}_{slte}}{\xi_{j-1}} \cdot \left(1 - \xi_{j-1}\right) + \dot{m}_{da} \cdot \omega_{j+1} - \frac{\dot{m}_{slte}}{\xi_{j}} \cdot \left(1 - \xi_{j}\right) - \dot{m}_{da} \cdot \omega_{j} = 0 \tag{1}$$

$$E_{H_2O,j} = P^{v}_{sltn}\left(T_j, \xi_j\right) - P^{v}_{air}\left(\omega_j, P\right) = 0 \tag{2}$$

$$H_j = \frac{\dot{m}_{slte}}{\xi_{j-1}} \cdot h^{L}_{j-1} + \dot{m}_{da} \cdot h^{G}_{j+1} - \frac{\dot{m}_{slte}}{\xi_{j}} \cdot h^{L}_{j} - \dot{m}_{da} \cdot h^{G}_{j} - \dot{Q}_j = 0 \tag{3}$$

This model allows calculating the temperature and concentration of the liquid desiccant solution leaving the absorber, the rate of heat that must be removed from the column, the mass flow of desiccant needed, the number of stages, and the temperature and concentration profiles of the liquid desiccant solution and humid air along the column. The model needs as inputs the temperature and absolute humidity of the air streams entering and leaving the absorber, the mass flow of dry air throughout the column, and the temperature and concentration of the solution entering the absorber. The enthalpy and vapor pressure of the desiccant solution must be provided as functions of temperature and solute mass fraction. Similarly, the enthalpy and vapor pressure of humid air must be provided as functions of temperature and absolute humidity.

3.2. Solution Heat Exchanger

Equation (4) gives the energy balance of the solution heat exchanger. The heat duty of the solution heat exchanger can be obtained by the application of Equation (4).

$$\dot{Q}_{SHX} = \dot{m}_{ws} \cdot (h_{ws3} - h_{ws2}) = \dot{m}_{ss} \cdot (h_{ss1} - h_{ss2}) \quad (4)$$

3.3. Regenerator

Equations (5) and (6) correspond to the mass and energy balances of the regenerator respectively. The temperature of steam leaving the regenerator is assumed as five degrees above the saturation temperature of the weak solution at the pressure of the regenerator, as indicated by Equation (7).

$$\dot{m}_v = \left(\frac{1}{\xi_{ws}} - \frac{1}{\xi_{ss}}\right) \cdot \dot{m}_{slte} = (\omega_{a2} - \omega_{a3}) \cdot \dot{m}_{da} \quad (5)$$

$$\dot{Q}_{reg} = \left[\left(\frac{1}{\xi_{ss}}\right) \cdot h_{ss1} - \left(\frac{1}{\xi_{ws}}\right) \cdot h_{ws3} + \left(\frac{1}{\xi_{ws}} - \frac{1}{\xi_{ss}}\right) \cdot h_{v1}\right] \cdot \dot{m}_{slte} \quad (6)$$

$$T_{v1} = T_{sltn}^{sat}(P_{reg}, \xi_{ws}) + 5 \quad (7)$$

3.4. Air-to-air heat exchanger and air heater

Equation (8) presents the energy balance of the air-to-air heat exchanger of the open configuration of the EELS system. On the other hand, Equation (9) defines the effectiveness of this heat exchanger. This definition takes into account that the stream with the lowest heat capacity is the ambient air stream entering the system. Equation (9) is important because it allows calculating T_{a1} by assuming the effectiveness of this heat exchanger. Finally, Equation (10) gives the heat duty of the air heater.

$$\dot{Q}_{AHX1} = \dot{m}_{da} \cdot (h_{a1} - h_{a0}) = \dot{m}_{da} \cdot (h_{a4} - h_{a5}) \quad (8)$$

$$\varepsilon_{AHX1} = \frac{T_{a1} - T_{a0}}{T_{a4} - T_{a0}} \quad (9)$$

$$\dot{Q}_{AHX2} = \dot{m}_{da} \cdot (h_{a2} - h_{a1}) \quad (10)$$

3.5. Energy savings

Equation (11) is useful for the calculation of the energy savings offered by both configurations of the EELS system considered in this paper. Equation (11) compares the overall energy consumption of the EELS system with the energy consumption of a reference system. The reference system is a conventional milk power SD without heat recovery for the production of 3000 kg/h of milk powder, dry basis. Equation (12) gives the heat input of the reference system, where the ambient temperature is assumed equal to 20 °C and the temperature of the drying air is assumed equal to 180 ºC. The mass flow of dry air for this SD is 20. kg/s.

The definition of the energy savings assumes that the steam produced in the regenerator of the EELS system is used elsewhere in the plant. Therefore, the heat released by condensing this steam represents energy savings for the system. The definition of the energy savings also assumes that the heat removed from the absorber by an external cooling medium is used elsewhere in the plant, and, therefore, this heat flow also represents energy savings for the system. On the other hand, it is important to highlight that $\dot{Q}_{AHX2}$ is zero for the closed configuration and that $\dot{Q}_{abs}$ is zero for the open configuration as it can be inferred from Fig. 1 and Fig. 2 respectively. Furthermore, this definition leaves out the power input of the solution pump because it is negligible in comparison with the heat flows.

$$ES = \frac{\dot{Q}_{ref} - \left(\dot{Q}_{reg} + \dot{Q}_{AHX2} - \dot{Q}_{abs} - \dot{Q}_{VHX}\right)}{\dot{Q}_{ref}} \times 100 \quad (11)$$

$$\dot{Q}_{ref} = \dot{m}_{da} \cdot (h_{a@180°C} - h_{a@20°C}) \quad (12)$$

4. Thermodynamic Properties

The mathematical model of the EELS system requires correlations for the calculation of the vapor pressure and enthalpy of aqueous phosphoric acid solutions. A literature review led to reported data of vapor pressure and enthalpy of phosphoric acid solutions, which allowed deriving the required correlations as functions of the temperature and concentration of the solution. On the other hand, the model also requires a correlation for the calculation of the enthalpy of humid air. This correlation was derived by using the ideal gas mixture approach and enthalpy data of water vapor and dry air obtained from Refprop.

4.1. Vapor pressure of aqueous phosphoric acid solutions

A correlation was derived for the calculation of the vapor pressure of phosphoric acid solutions. This correlation relates the vapor pressure of the solution with its temperature according to Antoine Equation, as shown in Equation (13). The coefficients A and B of Equation (13) were correlated from experimental data as third degree polynomials of the concentration of the solution.

$$\log(P_{sltn}^{v}) = A - \frac{B}{T} \tag{13}$$

The accuracy of this correlation was checked with reported experimental data [2], [4], and good agreement was found in the working range of the absorber.

4.2. Specific enthalpy of aqueous phosphoric acid solutions

The enthalpy of aqueous phosphoric acid solutions per unit mass of solution was calculated by using a correlation derived from the enthalpy data reported by Luff (1981) [7]. Equation (14) gives the derived correlation. Parameters ‘a’ and ‘b’ of Equation (14) were correlated as second degree polynomials of the concentration of the solution.

$$h_{sltn} = 1000 \cdot (a \cdot T - b) \tag{14}$$

5. Results

The mathematical model was useful for determining the thermodynamic limits of the closed and open configurations of the EELS system considered in this paper. The results presented in this section correspond to ideal systems working under ideal conditions.

5.1. Closed configuration

Table 1 summarizes the states of the main air and liquid desiccant streams obtained from the calculations concerning the closed configuration, and Table 2 shows the relevant mass and heat flows. Fig. 1 presents these results in a process flow diagram, and Fig. 3 shows the cycle of the liquid desiccant side on a pressure, temperature, concentration diagram (PTX diagram) of aqueous phosphoric acid solutions, which was obtained by using Equation (13). In the absorber, the dehumidification of the exhaust air is approximately isenthalpic because an external cooling medium removes 800 kW of heat that corresponds approximately to the difference between the heat of absorption and the latent heat of condensation of water vapor. The desiccant solution remains at subcooled conditions along the absorber as it is possible to see in the PTX diagram of Fig. 3 if taking into account that the absorber works at atmospheric pressure. It is also possible to see in the PTX diagram that the maximum temperature of the liquid desiccant is 400 °C, corresponding to the solution leaving the regenerator.

This configuration offers a percentage of energy savings of 99 % with respect to a SD without heat recovery. The calculation of energy savings by using Equation (11) considers that the heat rejected from the absorber is used for heating other processes in the plant and that the steam produced in the regenerator is condensed and subcooled down to 35 °C.

Table 1. Summary of temperatures and concentrations of the closed configuration

Property	SD	Abs.	Property	Abs.	SHX-Cold	Reg.	SHX-Hot

Air side			Liquid desiccant side				
T_{in} [ºC]	180	80	T_{in} [ºC]	185	107	285	400
T_{out} [ºC]	80	180	T_{out} [ºC]	107	285	400	185
ω_{in} [gkg^{-1}]	8	47	ξ_{in} [kgkg^{-1}]	0.754	0.68	0.68	0.754
ω_{out} [gkg^{-1}]	47	8	ξ_{out} [kgkg^{-1}]	0.68	0.68	0.754	0.754

Table 2. Summary of mass and heat flows of the closed configuration

Property	Value	Property	Value
$\dot{m}_{da}$ [kgs^{-1}]	20	$\dot{Q}_{abs}$ [kW]	800
$\dot{m}_{slte}$ [kgs^{-1}]	5.5	Q_{reg} [kW]	3157
$\dot{m}_{v}$ [kgs^{-1}]	0.8	$\dot{Q}_{ref}$ [kW]	3367
		Q_{VHX} [kW]	2339

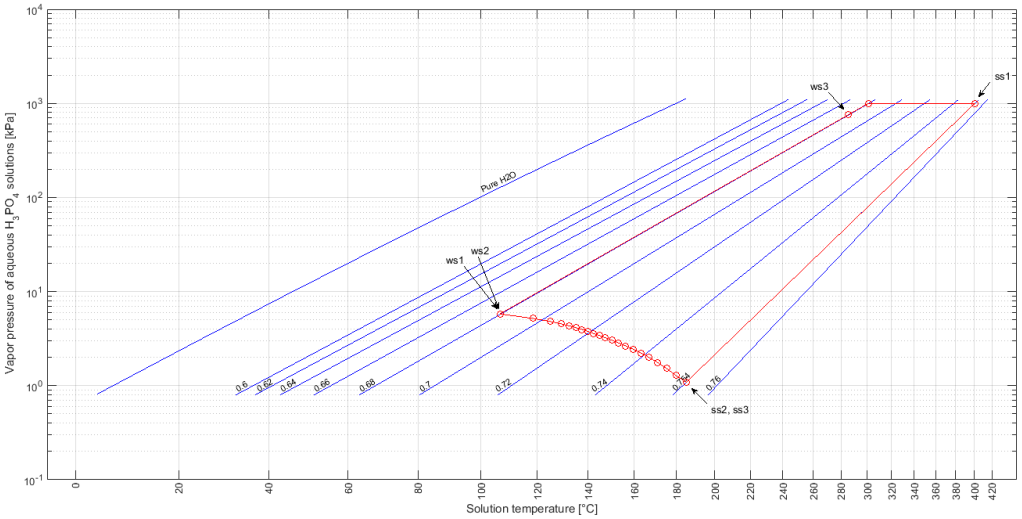


Fig. 3. P vs T diagram for aqueous solutions of phosphoric acid depicting the cycle on the liquid desiccant side of the EELS system. The concentration is expressed as the mass fraction of P_2O_5. The states correspond to the states of the connecting lines indicated in Fig. 1.

5.2. Open configuration

Fig. 4 shows a psychrometric chart depicting the process of the air side of the open configuration of the EELS system. As it is possible to see in Fig. 4, the absorber yields air at 198 ºC and 16 $g_{water}/kg_{dry\ air}$, a higher temperature and a higher absolute humidity in comparison with the previous case. This results from the use of an adiabatic absorber and from the fact that the liquid desiccant enters the absorber at a higher temperature, 203 ºC. Heating the exhaust air up to such a high temperature in the absorber is convenient in order to heat the ambient air entering the system up to a higher temperature in the exhaust-to-inlet-air heat exchanger. The effectiveness of this air-to-air heat exchanger was assumed equal to 75 %. Table 3 summarizes the states of the main air and liquid desiccant streams obtained from the calculations of the open configuration. These results are also indicated in Fig. 2. On the other hand, Table 4 summarizes relevant mass and heat flows. From Table 4, it is relevant to highlight that the mass flow of steam is smaller in the open configuration because less water is transferred from air to the desiccant solution in the absorber. This also leads to lower energy savings by condensation of steam in other processes of the plant.

This open configuration of the EELS system offers a percentage of energy savings of 58 %. Variables such as the number of stages of the absorber, the mass flow of desiccant, and mainly the effectiveness of the exhaust-to-inlet-air heat exchanger influence the energy savings achievable with this configuration.

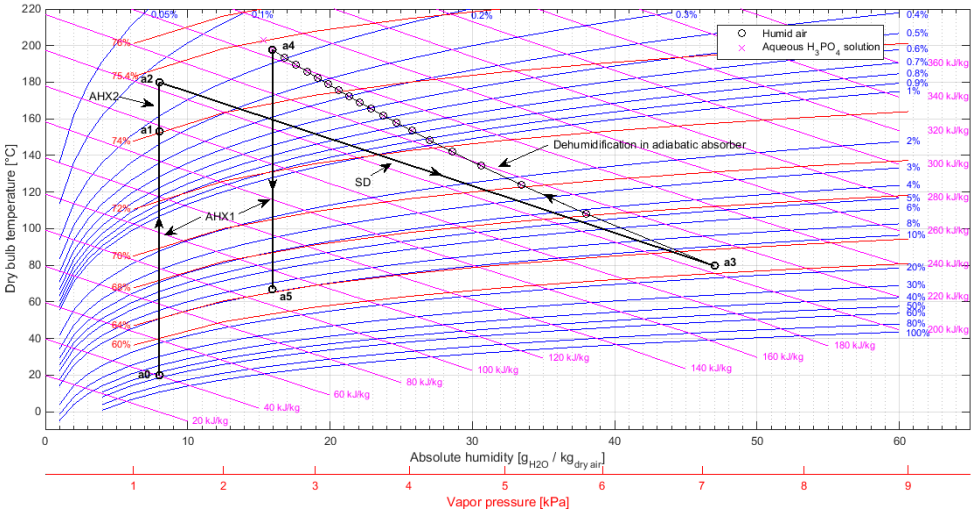


Figure 4. Psychrometric chart depicting the process of the air side of the open configuration of the EELS system

Table 3. Summary of temperatures and concentrations of the open configuration

Property	AHX1 cold	SD	Abs.	AHX1 hot	Property	Abs.	SHX cold	Reg.	SHX hot
	Air side					Liquid desiccant side			
T_{in} [ºC]	20	180	80	198	T_{in} [ºC]	203	108	273	400
T_{out} [ºC]	153	80	198	67	T_{out} [ºC]	108	273	400	203
ω_{in} [gkg^{-1}]	8	8	47	16	ξ_{in} [kgkg^{-1}]	0.754	0.68	0.68	0.754
ω_{out} [gkg^{-1}]	8	47	16	16	ξ_{out} [kgkg^{-1}]	0.68	0.68	0.754	0.754

Table 4. Summary of mass and heat flows of the open configuration

Property	Value	Property	Value
$\dot{m}_{da}$ [kgs^{-1}]	20	$\dot{Q}_{AHX2}$ [kW]	564
$\dot{m}_{slte}$ [kgs^{-1}]	4.5	$\dot{Q}_{reg}$ [kW]	2708
$\dot{m}_{v}$ [kgs^{-1}]	0.6	$\dot{Q}_{ref}$ [kW]	3367
		$\dot{Q}_{VHX}$ [kW]	1864

6. Conclusions

This paper described the EELS system proposed for the recovery of heat from the exhaust of milk powder spray dryers. It was found that aqueous phosphoric acid solutions have the required thermodynamic properties for the dehumidification of the exhaust air in the absorber in such a way that its latent heat is converted into sensible heat. Two configurations of the EELS system were evaluated from a thermodynamic point of view.

The closed configuration offers energy savings of about 99 % in comparison with a SD without heat recovery. In this configuration, heat enters the system only in the regenerator and leaves the system with the cooling medium of the absorber and with the steam flow from the regenerator. The temperature of these two streams is high enough for several heating applications in the plant. Therefore, under ideal conditions, 99 % of the energy input of this configuration is potentially recoverable.

On the other hand, the open configuration of the EELS system offers energy savings of 58 % with respect to the energy input of a conventional SD without heat recovery. In this case, heat enters the system in the regenerator and in an air heater and leaves with the exhaust air, vented after preheating the incoming ambient air, and with the steam flow from the regenerator. The absorber of this configuration is adiabatic. Energy is only recoverable from steam because the final temperature of the exhaust air is too low, 67 ºC. As a result, the energy savings are much lower in this case.

The simplicity and thus reduced cost of the adiabatic absorber makes the open configuration attractive from a practical point of view. Furthermore, this configuration eliminates the risk of contamination of milk powder with liquid desiccant.

For the conditions of the absorber, construction materials such as Hastelloy C and graphite composites can handle phosphoric acid solutions properly. For the conditions of the regenerator, there is a lack of suitable construction materials. Further research is needed in this direction.

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