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ABSTRACT

The manufacturing processes of industrial gases are major consumers of energy as electricity or fossil fuel. A big part of this energy ends up as heat in the process gas at temperatures around 150°C. Today, this thermal energy is generally released to the atmosphere through cooling towers.

In this paper, the recovery of waste heat by the production of cooling capacity is considered via a desiccant cooling cycle. The liquid desiccant dehumidification and regeneration processes, uses lithium chloride (LiCl) as a liquid desiccant. The numerical model is upgraded permitting the calculation of the exergy destruction due to water evaporation rate in the regenerator, the desiccant temperature and concentration at the exit of the regenerator.

An exergy analysis of the hot exhaust and the desiccant cooling cycle is performed, assessing the global exergy efficiency variation as a function of each operating parameter in the studied cycle and permitting the identification of the optimal design.

1. INTRODUCTION

The rising cost of energy and the global warming in recent years have highlighted the need to develop advanced energy systems to increase efficiency and to reduce emissions. Energy is universally acknowledged to be the mainstay of an industrial society. Without an adequate supply of energy, the stability of the social and economic order, as well as the political structure of a society is in jeopardy. As the world supply of inexpensive, but nonrenewable, fossil energy sources decreases, the need for energy conservation as well as for developing renewable technologies becomes ever more critical.

The industrial sector accounts for about one third of the total energy consumed in the world and is responsible for about one third of fossil fuel related greenhouse gas emissions. It is estimated that somewhere between 20 to 50% of industrial energy input is lost as waste heat in the form of hot exhaust gases, cooling water, and heat lost from hot equipment surfaces and heated products. As the industrial sector continues efforts to improve its energy efficiency, recovering waste heat losses provides an attractive opportunity for an emission free and less costly energy resource. Numerous technologies and variations/combinations of technologies are available for waste heat recovery. However, total or part of waste heat recovery is not possible in many cases.

The essential quality of waste heat is not the amount but rather its “value”. Waste heat has no useful application is found, and is regarded as a waste by-product. When produced by humans, or by human activities, it is a component of anthropogenic heat, which additionally includes unintentional heat leakage, such as from space heating. Waste heat is thought by some to contribute to the urban heat island effect.

Depending upon the type of process, waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

Many manufacturing processes of industrial gases are major consumers of energy as electricity or fossil fuel. A big part of this energy ends up as heat in the process gas at temperatures around 150°C. Today, this thermal energy is generally released to the atmosphere through cooling towers because the manufacturing processes don't need energy at this temperature level. However, this available energy in waste heat can be recovered for generation of steam, process heating and power generation. In the case studied, there is no use for heat at this temperature level, and an important need of air-conditioning and dehumidification is required.

The liquid desiccant evaporation cooling air conditioning system (LDCS) is an environmental friendly cooling technology and can be used to condition the indoor environment of buildings. Unlike conventional air conditioning systems, the system can be driven by low-grade heat sources such as solar energy or industrial waste heat.

Energy-driven liquid desiccant cooling systems (LDCS) can improve indoor air quality and reduce electrical energy consumption, and have been regarded highly by researchers and engineers in recent years (. The principle of their operation has been known for years. In the dehumidification process, the strong desiccant solution that has been brought into contact with the air absorbs the moisture from the air and gets diluted. After that, the desiccants must be regenerated to a useful level of concentration. Desiccant solutions such as LiCl–H2O can be regenerated by heat resources with low temperatures, such as industrial exhaust gas.

In this paper, the recovery of waste heat by the production of cooling capacity is considered via a desiccant cooling cycle. The liquid desiccant dehumidification and regeneration processes, uses lithium chloride (LiCl) as a liquid desiccant. The numerical model is upgraded permitting the calculation of the exergy destruction due to water evaporation rate in the regenerator, the desiccant temperature and concentration at the exit of the regenerator. An exergy analysis of the hot exhaust and the desiccant cooling cycle is performed, assessing the global exergy efficiency variation as a function of each operating parameter in the studied cycle and permitting the identification of the optimal design.

2. SYSTEM DESCRIPTION

2.1 Liquid desiccant cooling system

Liquid desiccant cooling systems have been proposed as alternatives to the conventional vapor compression cooling systems to control humidity, essentially in hot and humid areas. Research has shown that a liquid desiccant cooling system can reduce the overall energy consumption, as well as shift the energy use away from electricity and toward renewable and cheaper fuels (Oberg and Goswami, 1998a).

Use of liquid desiccants offers several design and performance advantages over solid desiccants, especially when solar energy is used for regeneration desiccants are commercially available: triethylene glycol, diethylene glycol, ethylene glycol, lithium chloride,… The usefulness of a particular liquid desiccant depends upon the application. Lithium chloride (LiCl) is a good candidate material since it has good desiccant characteristics and does not vaporize in air at ambient conditions.

Desiccant cooling has long been adopted for both industrial and agricultural purposes, and is now taking a more and more prominent role in the air-conditioning field. Desiccant dehumidification is economical and has effective humidity control at low and moderate temperature really dwarfs the conventional method of humidity control, since

it makes full use of surface vapor pressure difference to realize moisture transfer between the process air and the liquid desiccant.
LDCS have many advantages over solid ones, even though they give the same dehumidification effect. Indeed, LDCS have better humidity control, energy consumption, performance, indoor air quality, installation, weigh and maintenance; Also, the regeneration temperature required for liquid desiccants is lower than that of the solid desiccants; the pressure drop through a liquid desiccant system is smaller than the pressure drop through a solid desiccant wheel; liquid desiccants can be used as a heat transfer medium in a heat exchanger, and the energy is stored as chemical energy rather than thermal energy. We must talk also about the energy storage capacity, in liquid desiccants such as lithium chloride or calcium chloride is up to 3.5 times higher compared to solid desiccants such as zeolites or silica-gel related to the same dehumidification process.

2.2 Description of Basic liquid desiccant cooling system

The liquid desiccant system is composed mainly of: Dehumidifier, Regenerator, and heat exchangers. Figure 1 presents a schematic drawing of a liquid desiccant system. Dehumidifier is used to remove the moisture of the inlet air by bringing into contact with sprinkled liquid desiccant. It consists of: circulation pump, a strong desiccant tank, a weak desiccant tank, and a main blower. The strong desiccant is sprayed in a counter-flow direction and is brought in contact with blower air stream through packing material; strong desiccant absorbs humidity from air and converts to weak desiccant. Packing materials is the place where mass transfer occurs between falling film of the liquid desiccant and inlet air. Hence, the selection of packing materials will undoubtedly exert influence upon the performance of the dehumidification unit. Regenerator is used to regenerate the weak (diluted) solution flowing from dehumidification unit to an acceptable concentration. The regenerator is made up of a counter-flow packed bed regeneration tower similar to dehumidifier, a circulation pump, a strong desiccant tank, a weak desiccant tank, and a main blower. The weak desiccant is sprayed in a counter-flow direction and is brought in contact with hot air stream through packing material.

Heat exchangers are used to make a heat transfer between the weak and strong desiccant and between the external heat source and the weak desiccant to be regenerated, also between strong desiccant and cooling water.

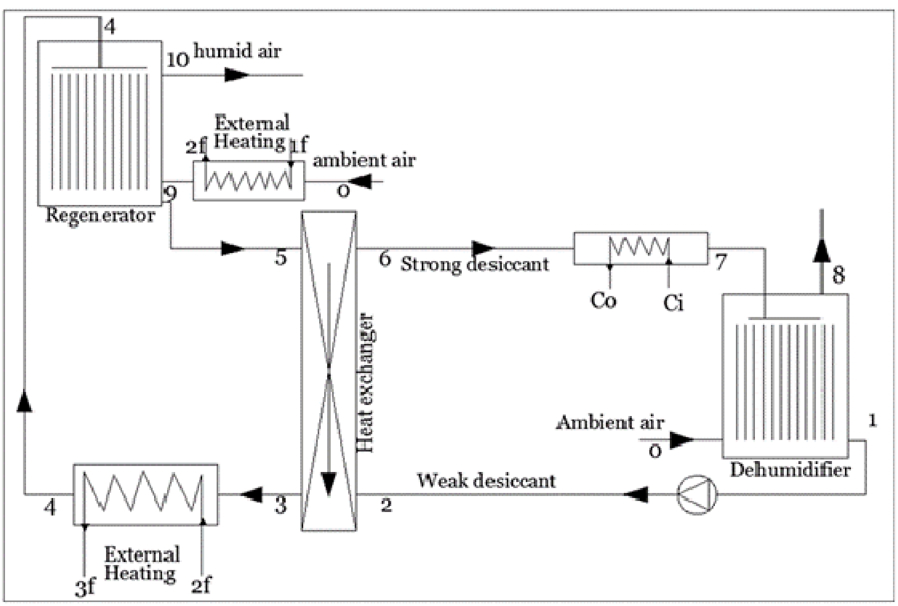

Figure 1: Schematic drawing of the liquid desiccant system

The dehumidification process is the most important part in the LDCS, since it can handle the total latent load in the air conditioning process; the task of dehumidification unit is to remove the moisture of the inlet air by bringing into contact with sprinkled liquid desiccant.

The surface vapor pressure difference between liquid-desiccant film and air is acting as the driving force for mass transfer of water vapor in the air to liquid water in the liquid desiccant (condensation process). The liquid desiccant has a vapor pressure lower than that of water at the same temperature and the air passing over the solution approaches this reduced vapor pressure and is dehumidified. Vapor pressure of a liquid desiccant is directly proportional to its temperature and inversely proportional to its concentration .As the desiccant content in the mixture increases its vapor pressure decreases.

To regenerate the liquid desiccant from the diluted liquid we must heat the last one, heating this solution will increase the liquid surface water pressure, hence the water is then evaporated to the external air where the partial pressure of the water vapor is less. The heat source in the studied case is the hot exhaust waste heat to recover.

Among many liquid desiccants available aqueous solution of Lithium chloride, Calcium chloride, Ethylene glycol; Lithium chloride is found to be most effective since it has the lowest vapor pressure among these.

Packed bed towers are more effective than the other methods of heat and mass transfer in the dehumidifier, since they provide large rate of heat and mass transfer per unit volume and hence a compact design is possible.

3. System analysis

3.1 Dehumidifier and regenerator models

For simulation purposes, validated models are required for modeling the absorber in a liquid desiccant system. Models using lithium chloride have been described by Khan and Martinez (1998), Ahmed *et al*. (1998) and Fumo and Goswani (2001). Gandhidasan (2004) developed a model for a packed bed liquid desiccant air dehumidifier with lithium chloride as liquid desiccant which was validated satisfactorily by the proposed. The present study uses this model.

According to Gandhidasan, the water flow rate condensed from the air to the desiccant solution can be predicted as a function of the air flow in the dehumidifier by the desiccant, the outlet desiccant concentration, and the outlet desiccant temperature. Accordingly, this can be defined as:

$$\dot{m} = \frac{1}{\lambda}\left[\frac{G_{s,deh}\, c_{P,s,deh}\, \varepsilon_{HE}}{(1-\varepsilon_{HE})}\left(t_7 - t_{c,i}\right) - G_{a,deh}\, c_{P,a}\, \beta\left(t_0 - t_7\right)\right] \tag{1}$$

$$X_{out} = \frac{G_{s,deh} \cdot S_{deh} \cdot X_{in}}{G_{s,deh} \cdot S_{deh} + m_{study}} \tag{2}$$

$$t_1 = \frac{t_7 - \varepsilon_{HE}\, t_{ci}}{1 - \varepsilon_{HE}} \tag{3}$$

Where λ, β and ε_{HE} are the latent heat of water, temperature difference ratio of the dehumidifier (4), and the temperature effectiveness of the cooling water-desiccant heat-exchanger (5).

$$\beta = \frac{t_0 - t_8}{t_0 - t_7} \tag{4}$$

$$\varepsilon_{HE} = \frac{t_6 - t_7}{t_6 - t_{ci}} \tag{5}$$

In order to identify the mass flow rate of the water evaporated from the desiccant solution an analogy between the dehumidifier and the regenerator is realized. A simplified model is developed, equation (6) represents the mass flow rate of the water that can be evaporated from the desiccant solution as a function of the desiccant solution and air inlet mass flow rate, the inlet and outlet temperatures of the air and the solution.

$$\dot{m} = \frac{1}{\lambda S_{reg}}\left[G_{s,reg} S_{reg} c_{P,s,reg}(t_4 - t_5) - G_{a,reg} S_{reg} c_{P,a} \beta (t_9 - t_4)\right] \quad (6)$$

$$\beta = \frac{t_9 - t_{10}}{t_9 - t_4} \quad (7)$$

The overall energy balance for the desiccant in the whole cycle can be written as:

$$Q_{solution\ heating} + Q_{dehumidifier} = Q_{regenerator} + Q_{solution\ cooling} \quad (8)$$

Equation (8) can be written as

$$\dot{m}_f(h_{2f} - h_{3f}) + G_{s,deh} S_{deh} c_{p,s,deh}(t_1 - t_7) = G_{s,reg} S_{reg} c_{p,s,reg}(t_4 - t_5) + \dot{m}_{cw}(h_{co} - h_{ci}) \quad (9)$$

Equation (9) permits to calculate the desiccant outlet temperature from the regenerator. Finally; the output desiccant concentration can be calculated from

$$X_{out} = \frac{G_{s,reg} . S_{reg} . X_{in}}{G_{s,reg} . S_{reg} - m_{study}} \quad (10)$$

3.2 Energy and exergy analysis of the system

The enegy and the exergy balance of each component is calculated following equations presented in table 1. By substituting the energy balance equation in the exergy balance equation; then the irreversibility rate can be written as shown in table 2.

Table 1: Equation set of energy and exergy balance I each component of the system

Energy balance	***Exergy balance***
Regenerator	
$\dot{m}_{ar}(h_9 - h_{10}) + \dot{m}_w h_4 - \dot{m}_s h_5 = 0$	$\dot{m}_{ar}(ex_9 - ex_{10}) + \dot{m}_w ex_4 - \dot{m}_s ex_5 - \dot{E}x_{d,reg} = 0$
Dehumidifier	
$\dot{m}_{ad}(h_0 - h_8) + \dot{m}_s h_7 - \dot{m}_w h_1 = 0$	$\dot{m}_{ad}(ex_0 - ex_8) + \dot{m}_s ex_7 - \dot{m}_w ex_1 - \dot{E}x_{d,deh} = 0$
Cooling water heat exchanger (CWHX)	
$\dot{m}_{cw}(h_{ci} - h_{co}) + \dot{m}_s(h_6 - h_7) = 0$	$\dot{m}_{cw}(ex_{ci} - ex_{co}) + \dot{m}_s(ex_6 - ex_7) - \dot{E}x_{d,CHWE} = 0$
Solution heat exchanger (SHX)	
$\dot{m}_w(h_2 - h_3) + \dot{m}_s(h_5 - h_6) = 0$	$\dot{m}_w(ex_2 - ex_3) + \dot{m}_s(ex_5 - ex_6) - \dot{E}x_{d,SHX} = 0$
External Heating of the regenerator inlet air (EHRIA)	
$\dot{m}_f(h_{1f} - h_{2f}) + \dot{m}_{ar}(h_0 - h_9) = 0$	$\dot{m}_f(ex_{1f} - ex_{2f}) + \dot{m}_{ar}(ex_0 - ex_9) - \dot{E}x_{d,EHRA} = 0$
External Heating of the weak desiccant (EHWD)	
$\dot{m}_f(h_{2f} - h_{3f}) + \dot{m}_w(h_3 - h_4) = 0$	$\dot{m}_f(ex_{2f} - ex_{3f}) + \dot{m}_w(ex_3 - ex_4) - \dot{E}x_{d,EHWD} = 0$

Table 2: Exergy destruction in each component

Component	***Exergy destruction***
Regenerator	$\dot{I}_{reg} = \dot{E}x_{d,reg} = T_o(\dot{m}_{ar}(s_{10} - s_9) + \dot{m}_s s_5 - \dot{m}_w s_4)$
Dehumidifier	$\dot{I}_{deh} = \dot{E}x_{d,deh} = T_o(\dot{m}_{ad}(s_8 - s_0) + \dot{m}_w s_1 - \dot{m}_s s_7)$
CWHX	$\dot{I}_{CWHE} = \dot{E}x_{d,CWHE} = T_o(\dot{m}_{cw}(s_{co} - s_{ci}) + \dot{m}_s(s_7 - s_6))$
SHX	$\dot{I}_{SHX} = \dot{E}x_{d,SHX} = T_o(\dot{m}_w(s_3 - s_2) + \dot{m}_s(s_6 - s_5))$
EHRIA	$\dot{I}_{EHRA} = \dot{E}x_{d,EHRA} = T_o\left(\dot{m}_f(s_{2f} - s_{1f}) + \dot{m}_s(s_9 - s_0)\right)$
EHWD	$\dot{I}_{EHWD} = \dot{E}x_{d,EHWD} = T_o\left(\dot{m}_f(s_{3f} - s_{2f}) + \dot{m}_w(s_4 - s_3)\right)$

Finally the internal exergy destruction of the global system is the sum of the individual exergy destruction at each component:

$$\sum_i \dot{E}x_{d,i} = \dot{I}_{reg} + \dot{I}_{deh} + \dot{I}_{CHWE} + \dot{I}_{SHX} + \dot{I}_{EHRA} + \dot{I}_{EHWD} \quad (11)$$

The exergy loss in the hot flow is between 3f and downstream 4f, and the available exergy in the flow between points 1f and 4f, thus we can calculate the global exergy efficiency of the system. As shown in figure 2, energy is recovered from the hot exhaust between points 1f and 3f to heat the air and the desiccant solution entering the regenerator.

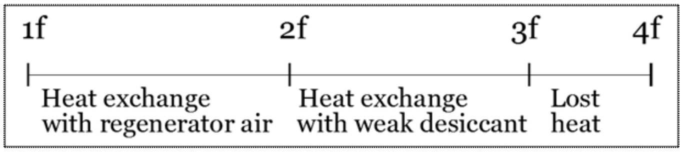

Figure 2: Heat exchange with the hot flow profile

The calculation of the thermodynamic properties of the different points of the system is performed by using REFPROP for air, water and flue gaz flows. Thermodynamic properties of the LiCl-H_2O solution are calculated using the model developed by Patek and Klomfar (2008).

4. Results and discussions

The effect of various design variables such as air flow rate, desiccant solution flow rate, desiccant concentration and outlet gas temperature from heat exchangers on the global exergy efficiency of the system was studied. Parameters that have been kept constant are listed in table 3. Table 4 below shows the different properties of the desiccant cycle at almost all the points that can reflect the behavior of the cycle according to some specific operating conditions using LiCl as a desiccant.

Table 3: LDCS parameters for the parametric investigation

Parameter	***Value***
Inlet desiccant concentration in the dehumidifier, Xi	11 % by mass
Inlet desiccant temperature in the dehumidifier, T_7	30 °C
Desiccant flow rate, $G_{s,d}$	8,4 kg/m².s
Air flow rate	1,5 kg/m².s
Ambient air Temperature, T_0	30 °C
Inlet air humidity ratio, Wi	0,0181 kg/kg dry air
Dimensionless temperature difference ratio in the dehumidifier, β_{deh}	10,5
Dimensionless temperature difference ratio in the regenerator, β_{deh}	1,165
Heat exchanger effectiveness, ε	0,6

Table 4: State properties of the desiccant cycle at operating conditions mentioned in table 3

Points	Fluide	Temperature (°C)	X (kg LiCl/kg sol)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)
1f	exhaust gas	165,0	-	459,5	6,0162
2f	exhaust gas	138,0	-	431,8	5,9509
3f	exhaust gas	45,0	-	336,6	5,6884
4f	exhaust gas	25,0	-	326,0	5,6219
ci	water	29,0	-	121,2	0,4208
co	water	30,5	-	127,5	0,4415
0deh	air	30,0	-	349,6	7,0411
0reg	air	30,0	-	349,6	7,0411
1	weak sol	31,9	10,97	107,2	0,4597
2	weak sol	31,9	10,97	107,2	0,4597
3	weak sol	39,5	10,97	134,7	0,5487
4	weak sol	39,0	10,97	132,9	0,5431
5	strong sol	37,8	11,00	128,6	0,5294
6	strong sol	31,5	11,00	105,7	0,4549

7	strong sol	30,0	11,00	100,2	0,4370
8	air	30,0	-	319,0	6,9354
9	air	43,2	-	320,9	7,0855
10	humid air	38,3	-	400,4	7,1753

The pie chart presented in figure 3 shows the contribution of the different components in the cycle in the overall irreversibility rate according to the specific conditions of table 3. The major irreversibilities are in the heat loss where energy is not totally recovered, and in the heat exchanger (EHRIA) because of the important temperature difference between the hot and the cold flux.

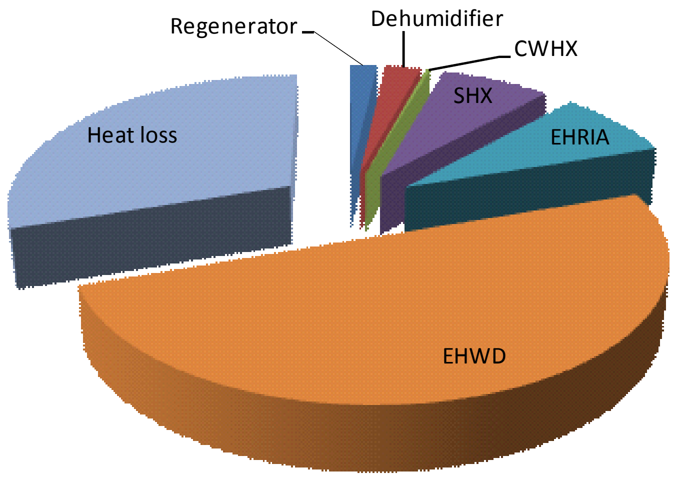

Figure 3: Contribution of each component in the overall irreversibility rate

Figure 4 shows the effect of the temperature of the hot flow at the end of the heat exchange with the regenerator air on the global exergy efficiency, this figure shows clearly that the global exergy efficiency increases with the increase of T_{2f} .

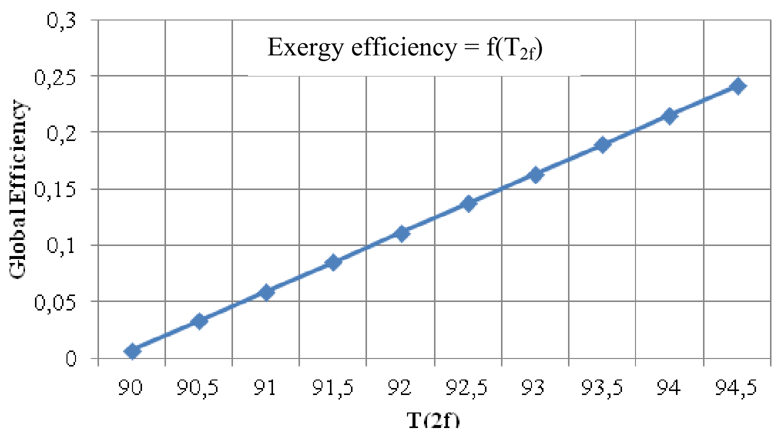

Figure 4: Influence of the hot flow temperature at the end of heat exchange with the regenerator inlet air on the global exergy efficiency

Figure 5 shows the effect of the ambient air absolute humidity on the global exergy efficiency, it clearly shows that the global exergy efficiency increases with the increase of the absolute humidity by a slope of 290 %/(kg/kg). The maximum exergy efficiency that can be obtained by the system is the value of T3f equal to the desiccant solution inlet temperature in the system.

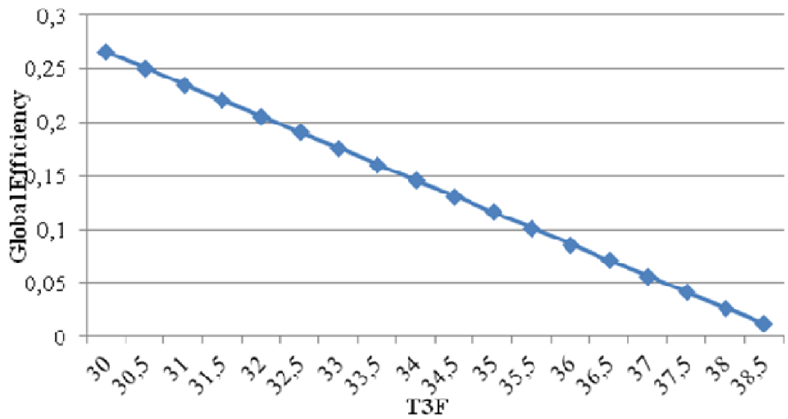

Figure 5: Influence of the hot flow temperature at the end of heat exchange with the weak desiccant on the global exergy efficiency

Figure 6 shows the effect of the dehumidifier desiccant specific mass flow on the global exergy efficiency, it clearly shows that the global exergy efficiency decreases with the increase of the specific flow. Figure 7 shows the effect of the dehumidifier air specific mass flow on the global exergy efficiency, it clearly shows that the global exergy efficiency increases with the increase of the specific flow.

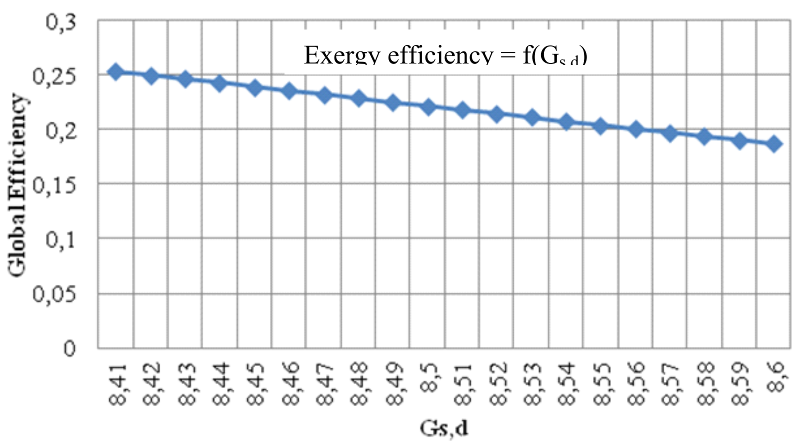

Figure 6: Influence of the dehumidifier desiccant specific flow on the global exergy efficiency

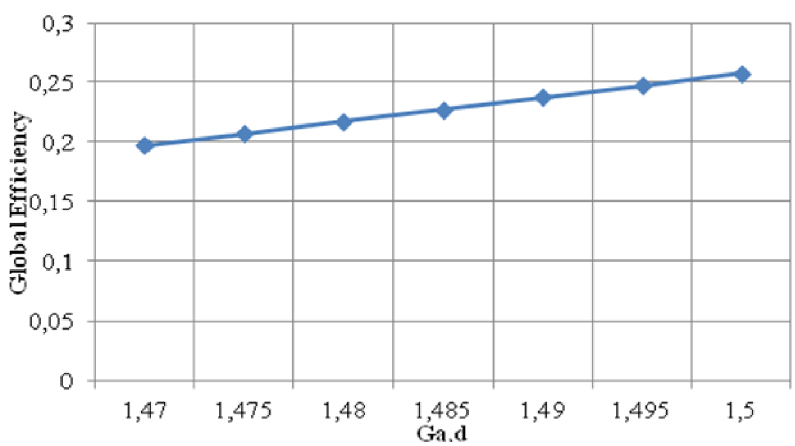

Figure 7: Influence of the dehumidifier air specific flow on the global exergy efficiency

The effect of the dehumidifier inlet desiccant concentration on the global exergy efficiency is evaluated. Figure 8 clearly shows that the global exergy efficiency increases with the increase of the concentration by a slope of 4.01 %/(kg/kg).

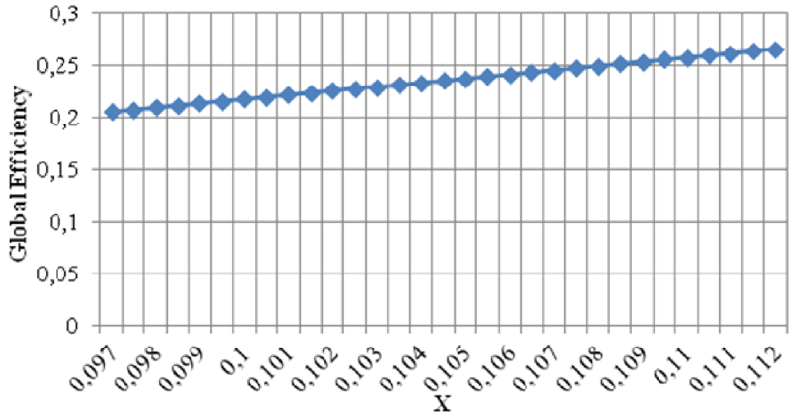

Figure 8: Influence of the dehumidifier inlet desiccant concentration on the global exergy efficiency

5. CONCLUSIONS

The recovery of waste heat by the production of cooling capacity is considered via a desiccant cooling cycle. The liquid desiccant dehumidification and regeneration processes, uses lithium chloride (LiCl) as a liquid desiccant. The numerical model is upgraded permitting the calculation of the exergy destruction due to water evaporation rate in the regenerator, the desiccant temperature and concentration at the exit of the regenerator. A parametric analysis was performed on some design variables, and the behavior of the global exergy efficiency was studied as a function of each operating parameter in each cycle. Reliable sets of data for air dehumidification and desiccant regeneration using lithium chloride were obtained. Therefore, the slope of the curves in figures 4 to 8 give a measurement of the impact of the variable on the global exergy efficiency of the system. Hence, one can see that the global exergy efficiency:

- Increases with the increase of the air flow rate in the dehumidifier, the increase of the salt concentration and with the increase of the temperature of the exhaust gas at T2f
- Decreases with the increase of the exhaust temperature from the EHWS (T_{3f}) and with the increase of the desiccant solution mass flow rate.

NOMENCLATURE

H	enthalpy of a unit mass	($kJkg^{-1}$)	***Subscripts***	
ex	exergy of a unit mass	($kJkg^{-1}$)	s	strong
T	temperature	(K) or (°C)	w	weak/water
s	entropy of a unit mass	($kJkg^{-1}K^{-1}$)	f	flow
Q	heat	(J)	d	destruction
X	mass fraction of the desiccant	(%)	g	global
P	pressure	(bar)	abs	absorber
Y	air absolute humidity	(kg/kg)	***Greek symbols***	
Gs,deh	specific desiccant flow in the dehumidifier	(kg/m².s)	η	efficiency
Ga,deh	specific air flow in the dehumidifier	(kg/m².s)	β	temperature difference ratio
Gs,red	specific desiccant flow in the regenerator	(kg/m².s)	ε	effectiveness
Ga,reg	specific air flow in the regenerator	(kg/s.m2)		

REFERENCES

Ahmed Khalid C. S., Gandhidasan P., Zubair S. M. and Al-Farayedhi A. A. (1998) Exergy analysis of a liquid desiccant based air-conditioning system. Energy vol. 23, p 51- 59.

Al-farayedhi A., Gandhidasan P., Antar M. A. & Abdul gaffer S., 2002, Experimental study of hybrid liquid desiccant based vapor compression cooling system; The 6th saudi engineering conference, kfupm, dhahran, December, vol. 5, p 503.

Fumo and Goswani, 2002, Study of an aqueous lithium chloride desiccant system: air dehumidification and desiccant regeneration. Solar Energy Vol. 72, . 351–361.

Gandhidasan P., 2004, A simplified model for air dehumidification with liquid desiccant; Department of mechanical engineering, King Fahd university of petroleum and minerals, dhahran 31261, saudi arabia; solar energy vol 76 409–416

Khan A. Y. and Martinez J., 1998, Modeling and parametric analysis of heat and mass transfer performance of a hybrid liquid desiccant absorber. Energy Convers. Manage. Vol. 39, p 1095–1112.

Kishore, Dilip D, Experimental analysis of a hybrid liquid desiccant dehumidification system, Department of mechanical engineering, college of engineering, thiruvananthapuram, kerala.

Oberg V. and Goswami D. Y., 1998, Performance simulation of solar hybrid liquid desiccant cooling for ventilation air preconditioning. In Solar Engineering 1998, Proceedings of the International Solar Energy Engineering Conference, pp. 176–182, ASME, Fairfield, NJ.

Patek J., Klomfar J., 2008,; Thermodynamic properties of the LiCl–h2o system at vapor–liquid equilibrium from 273 K TO 400 K. Int. J. of Refrigeration, vol 31, 287 – 303.