

Regenerator for Liquid Desiccant Air Conditioning System

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Abstract— Energy conservation in air conditioning systems is essential as the fuel prices are increasing day-by-day and the deep concerns of shortages. The application of Liquid Desiccant (LD) in Air Conditioning System can be energy efficient and environmental friendly. The desiccant air conditioning systems (LDACS) systems have ability to provide required humidity and temperature for human comfort while reducing the electrical energy requirement compared to a Vapor Compression System (VCS) alone. The LDACS consists of vapour compression and LD cycles. A 1.5 ton desiccant cooling system with R-22 refrigerant and calcium chloride LD is designed fabricated and tested. This paper presents design, fabrication and testing of regenerator which is the part of LD cycle. Initially the system is tested with water and later on with CaCl₂. The results show that the specific moisture exaction rate from the LD is 2.14 kg/kW-h and the cooling capacity increases by 30 %. The increase in cooling capacity is due to addition of liquid desiccant (LD) cycle with conventional vapor compression cycle.

Key words: Air-Conditioning, Liquid Desiccant, Calcium Chloride, Regenerator

I. INTRODUCTION

The entire world is focusing on energy conservation in air conditioning to reduce the CO₂ emissions and cost of power. Desiccant cooling technology for air conditioning systems has been continuously proving to be more effective alternative to the conventional VCS. In a conventional VCS, air is cooled below the Apparatus Dew Point (ADP) temperature so that the moisture can be removed due to condensation. The cooled and dehumidified air is then reheated to the desired temperature and relative humidity which is resulting more power consumption. In liquid desiccant air conditioning system (LDACS), the moisture from the air to be conditioned is absorbed by the cool LD solution, thus cooling air by giving out its heat to the LD. Since the air is dehumidified by the LD,

only sensible cooling is required to be handled by the VCS thereby allowing evaporator coil to be operated at higher temperatures in regard to conventional VCS. Thus the hybrid system with combination of LD and VCS operates on less energy input than the conventional system [1], [2].

Fig. 1 shows the schematic of the LDACS. The system consists of desiccant cycle and VCC. The VCS operates between condenser temperature of 45°C and evaporator temperature of 15°C. The evaporator coil is immersed in a tray filled with LD, calcium chloride (CaCl₂) solution having 30% concentration by weight. The refrigerant absorbs the heat from this solution thereby reducing its temperature. The low temperature LD flows through a absorber contacting device for room air and LD, forming a layer over the surface of these meshes.

The air to be conditioned is forced to flow through these meshes in horizontal direction by using a fan. The air while flowing across the meshes comes in contact with the cool LD, flowing in vertical direction. The CaCl₂ solution absorbs the moisture from the flowing air and there is a simultaneous cooling of air as it comes in contact with the cool LD. The CaCl₂ solution becomes weak after absorbing the moisture from the air as its concentration by weight falls. This weak CaCl₂ solution then flows under gravity to the other tray in which the condenser coils of VCS are immersed. The refrigerant used in the VCS rejects its heat to the condenser coil. The temperature of the CaCl₂ solution rises as it absorbs the heat rejected by the condenser coil. The high temperature weak CaCl₂ solution then flows through a regenerator contacting device for ambient air and LD, forming a layer over its surface. While flowing, the CaCl₂ solution rejects its moisture to the ambient air that is forced to flow in perpendicular direction. The mass transfer of the moisture from

the CaCl_2 solution to the ambient air takes place because of the partial pressure difference of CaCl_2 in the solution and the air. The air also takes away the heat from the CaCl_2 solution lowering its temperature. The CaCl_2 solution leaving the regenerator is now strong as concentration by weight of CaCl_2 in the solution increases as a result of moisture removal from the CaCl_2 solution. This strong CaCl_2 solution is then pumped to the evaporator tray through a solution heat exchanger where it further gives away its heat to the weak solution coming from the absorber.

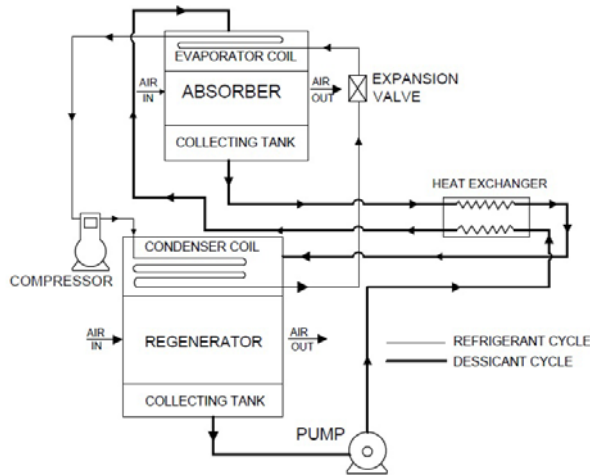


Figure 1. Schematic layout of LDACS

The regenerated hot and concentrated LD flowing to absorber is cooled in the solution heat exchanger by the cool stream of weak LD flowing in the counter flow direction to the regenerator. This paper presents the design, fabrication and testing of regenerator.

II. REGENERATOR

In the process of regeneration of liquid desiccant (LD), the challenges have been to make the process techno-economically viable by designing features to meet the needs of regeneration and achieve with significant reduction of thermal energy and auxiliary power requirement for pumping LD and blower power for circulating the air. The equipment often employed for regeneration process of LD are packed bed regenerators, spray towers with finned tube heat exchangers, solar regenerator, simple boiler and multiple effect boiler [3].

Packed towers are widely used for regeneration process of LD [4]. In packed towers, the desiccant is distributed over the packing by spray heads and the process air was blown through the packing for regeneration of LD. The process air picks up the water from the LD because of the partial pressure difference of water in the process air and LD. The main problem associated in this regeneration process is carryover of LD along with air stream.

Spray chamber with finned tube heat exchanger is the practical equipment for regeneration process of LD [5]. Finned tube heat exchangers are stacked horizontally with a

column with hot water flowing in the tube side. LD was sprayed on the heat exchanger and drips down. A blower was used to circulate process air through the regenerator counter current to the falling LD. The advantage of the system is a lower pressure drop for the airside. However, there is a relatively high pumping cost for spraying the LD. The tendency for carryover of liquid by the air is considerable in the spray towers and mist eliminators will almost always be necessary leading to increase the air side pressure drop. Even with mist eliminators 100% elimination of carryover is not ensured.

Regeneration of LD can be done using solar energy. A solar regenerator consists of inclined surface with transparent glazing as a covering where weak LD that is to be regenerated flows down the sloping surface as a falling film and is heated by the absorbed solar radiation [5]. The water vapour that is evaporated from the solution surface is removed by blowing air through the slot formed between the glazing and the film surface. Solar collector cum desorber was discussed in [6]. The corrugated galvanised iron sheet was used as the solar collector to regenerate calcium chloride LD. The disadvantage of the solar regeneration process is that the system cannot be operated during non-solar hours. There must be a backup heat source for the regeneration of LD during non-solar hours.

A Hybrid Vapour Compression/Liquid Desiccant Air Conditioner system [7] consisting of a compressor, evaporator, condenser and refrigerant. LD and refrigerant are simultaneously circulated between evaporator and condenser for cooling and dehumidifying air forced therein. The regeneration of the LD is achieved by spraying the LD on the condenser of vapour compression refrigeration system. A blower is provided to circulate the outdoor air to regenerate the LD. The main problem with such arrangement is corrosion of the condenser coil. Moreover, as the LD is sprayed, the loss of LD to indoor and outdoor air streams takes place [3].

Various prototypes of regenerators are developed during the course of work. These devices incorporate large surface density which makes them compact. There is no carryover of LD from these devices. Design, development and testing of the regenerator are presented in the subsequent sections of this paper.

III. DESIGN OF REGENERATOR

The strong LD is cooled by losing heat to the refrigerant in condenser coil in the tray and then sprayed over the contacting device for losing moisture to the ambient air. The various parameters considered for the design of the regenerator are shown in the Table 1.

TABLE 1: PARAMETERS OF LDACS FOR SIMULATION.

T_{dbi}	26 °C	Φ_i	70%
T_{dbo}	30 °C	Φ_o	80%
T_{cacl2i}	30 °C	C_{cacl2i}	30
T_{cacl2o}	40 °C	C_{cacl2o}	40

A blower is provided to give required air velocity over the regenerator. The simulation is carried out for the moisture lost by the LD based on mass transfer basis.

Mass transfer coefficient is given by (1).

$$hm_{ab} = (St_{ab} \cdot \rho_a \cdot V_a) / P_{a.ab.lmpd} \quad [8] \quad (1)$$

Total mass of water transferred to calcium chloride solution,

$$m_{w.ab} = hm_{ab}(A_{s.ab})lmpd_{ab} \quad (2)$$

The length of condenser coil is calculated with the correlations for condensation in tubes used in [9].

To find total surface area,

$$A_{s.ab} = L*B_1*8 + L*B_2*8 + \dots \quad (3)$$

L = length of Mesh = 0.5 m

B = consecutive breadth = variable

Surface area = 29.04 m²

Volume = $L*B*H$ = 0.125 m³

Where,

$L = B = H = 0.5$ m

Contact Surface Area = Total Surface Area/Volume = 232m²/m³

IV. FABRICATION OF REGENERATOR

Regenerator is made with the help of acrylic rods and netlon mesh. Acrylic sheets were cut into rods using laser cutting machine. Then the acrylic rods were stuck together using super glue and silicon glue and was made in a shape of a cubical box as shown in Fig. 2 and Fig. 3. Then the netlon mesh was cut into required dimensions and stuck it over the box. Similarly 21 more boxes were made and stuck the meshes. The outer box's dimensions are 50cm x 50cm and other boxes dimensions are reduced by 5 mm each respectively. To give extra strength and to hold the mesh firmly we tied the mesh with nylon threads. The details of the construction are shown in Fig. 2, Fig. 3 and Fig. 4. The complete assembly of regenerator is shown in Fig. 5.

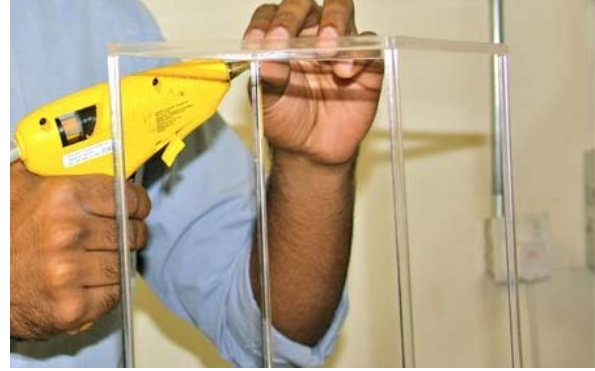


Figure 2. Sticking of acrylic using silicon glue



Figure 3. After sticking of acrylic



Figure 4. Construction of the mesh

After the completion of the mesh we placed the mesh in a fiber square box of dimension 51cm X 51 cm. Fig. 5 shows the completely fabricated absorber.



Figure 5. Regenerator

V. RESULTS AND DISCUSSION

Fig. 6 shows the measurement of DBT and WBT. Table 2 represents test readings with CaCl₂ solution. Fig. 7 shows the representation of DBT and WBT of air on Psychrometric chart.



Figure 6. DBT and WBT measurement

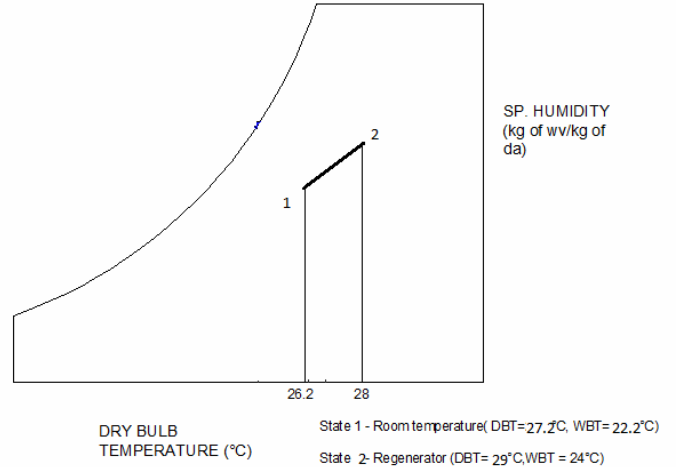


Figure 7. Representation of DBT and WBT of air on Psychrometric chart.

Moisture removal from LD in the Regenerator-

m_a = mass flow rate of air

$$m_a = \rho v A \quad (4)$$

$$v = 2.5 \text{ m/s}$$

$$v = 0.865 \text{ m}^3/\text{kg}$$

$$m_a = (0.25 \times 2.5) / 0.865$$

$$= 0.722 \text{ kg/s}$$

Specific humidity change (Readings taken from Table 2)

$$\omega_1 = 0.0145 \text{ kg of wv / kg of da} \quad (\text{DBT}=27.2^\circ\text{C}, \text{WBT} = 22.2^\circ\text{C})$$

$$\omega_2 = 0.0165 \text{ kg of wv / kg of da} \quad (\text{DBT}=29^\circ\text{C}, \text{WBT} = 24^\circ\text{C})$$

Moisture lost by desiccant to ambient air.

$$m_v = m_a \times (\omega_2 - \omega_1) \quad (5)$$

$$= 0.722 (0.0165 - 0.0145) = 1.445 \times 10^{-3} \text{ kg/s}$$

Total power consumption including compressor power, pump power and fan power.

$$W = 2.43 \text{ kW}$$

Specific Moisture Extraction Rate (SMER)

$$= m_v / W \quad (6)$$

$$= 2.14 \text{ kg/kW-h}$$

TABLE 2: TEST READINGS WITH CaCl₂ SOLUTION

Sl. No.	Ambient temperature		Air outlet at Absorber		Air outlet at regenerator		Liquid temperature in Evaporator		Liquid temperature in Condenser	
	DBT (°C)	WBT (°C)	DBT (°C)	WBT (°C)	DBT (°C)	WBT (°C)	IN (°C)	OUT (°C)	IN (°C)	OUT (°C)
1.	26.7	22	27	27	28	23	32	26	35	39
2.	27.2	22.2	28	27	29	24	34	25	33	39
3.	28	22.8	28	26	29.5	24	34	26	33	39
4.	28	22	28	27	30	23	33	25.5	33	38

VI. CONCLUSION

The box in box type contacting device for the regenerator has the large surface density of 232 m²/m³. The testing of the contacting device has confirmed that there is no carryover of LD in the air stream. The regenerator of LDACS is effectively used the heat rejected by the condenser of vapor compression cycle. The specific moisture exaction rate is 2.14 kg/kW-h which is significantly higher than the conventional LD regenerators. The cooling capacity of LDACS is 30 % greater than the conventional VCS for the conditioning of same mass flow rate of air.

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NOMENCLATURE

A	Area	m ²
C	Co. V. ncentration	%
Cp	specific heat	kJ/kg.K
Hm	mass transfer coefficient	kg/(m ² .Pa.s)
Lmpd	log mean pressure difference	kPa
M	mass flow rate	kg/s
P	Pressure	kPa
Q	heat flow	kW
SMER	Specific Moisture Extraction Rate	kg/kW-h

St	Stanton number	Dimensionless
T	Temperature	°C
V	Velocity	m/s
Ω	specific humidity	kg/kg of dry air
Φ	relative humidity	%
P	Density	kg/m ³
Lat	Latent heat	kJ/kg

REFERENCES

- [1] M. V. Rane, S. V. Kota Reddy, and J. S. Bajaj, "Cooling & dehumidification using liquid desiccant", Proc. of the International Sorption Heat Pump Conference, Shanghai, pp. 414-418, Sept.2002.
- [2] S. V. K. Reddy, G. I. Panchal, and A. B. Salvi, "Ammonia-liquid desiccant based hybrid air conditioning sytem", Proceedings of internal conference on Ammonia Refrigeration Technology for Today and Tomorrow, Ohrid, Macedonia, 2007.
- [3] S. V. K. Reddy, "Development of energy efficient solar/desiccant based drying system", Ph.D Thesis, Mechanical Engineering Department, IIT Bombay, India, 2003.
- [4] V. Martin, and D. Y. Goswamy, "Heat and mass transfer in packed bed liquid desiccant regenerators - an experimental investigation", Journal of Solar Energy Engineering, Transactions of the ASME, Vol. 121, pp.163-169, USA, 1999.
- [5] C. S. P. Peng, and J. R. Howell, "The performance of various types of regenerators for liquid desiccants", Journal of Solar Energy Engineering, Transactions of the ASME, Vol. 106, pp. 133-141, USA 1984.
- [6] S. C. Mullick, and M. C. Gupta, "Solar desorption of absorbent solutions", Solar Energy, 16, pp. 19-24, 1974.
- [7] S. L. Peterson, and J. R. Howell, "Hybrid vapour compression/liquid desiccant air conditioner", US Patent No. 4,941,324, 1990.
- [8] Robert Ewald Treybal, McGraw-Hill Companies, 3rd Edition, Mass Transfer Operations, 1980.
- [9] J. R. Thome, "Desiccant Evaporator in plain horizontal tubes: Recent advances in modelling of heat transfer to pure fluids and mixtures", Journal of the Braz. Soc. of Mech. Sci. & Eng. Vol. XXVII No. 1/23, Jan-Mar 2005.

AUTHORSPROFILE

Dr. S. V. Kota Reddy has 23 years of teaching and research experience. He has completed Ph. D programme in IIT Bombay in 2003. Dr. Reddy published more than 20 research papers in Journals, International and National Conference. He filed seven patents, one US, two International and four Indian, in association with IIT Bombay.

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His R&D project on “Plastic Solar Water Heater” won the Meritorious Award at KAIF 2007, a State Level Project Exhibition Organized by TATA Power, Mumbai. Dr. Reddy’s R&D projects on “Heat Pump Assisted Dryer” and “Hybrid Air Conditioning System” won the National Award for INR. 1,00,000/- and INR 50,000/- for Excellence in HVAC&R instituted by Bry-Air Asia Pvt. Ltd. in the year 2008 and 2009 respectively (<http://www.bryairawards.com/>). He is the life member of Indian Society of Heating, Refrigeration and Air Conditioning Engineers (ISHRAE). He served the ISHRAE Mumbai Chapter at various positions as a Chapter Working Committee Member, 2004-05, 2005-06, Treasurer, 2006-07, Secretary, 2007-08 and 2008-09. He was ISHRAE Student Chair, Western Region (Maharashtra, Gujarat and Goa) in the year 2008-09. He was the ISHRAE Students’ Activities Chair, Hyderabad in the year 2009. He worked as Principal of Medha College of Engineering, Hyderabad from November 2008 to 7th August 2009. He joined as Chairperson of Engineering Department, Manipal University Dubai Campus on 15th August 2009. Dr. Reddy visited Germany and Thailand for inspection of the state of the art equipment purchased for various labs in the Department. He is the member of ASHRAE (American Society of Heating, Refrigerating and Air conditioning Engineers). Dr. Reddy is the ASHRAE student branch advisor. He is currently working on project titled “Solar liquid desiccant air conditioning system” funded by ASHRAE, USA. He is the approved guide of Manipal University, India to guide Ph. D. students in Mechanical Engineering.

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Mr. Manish Jangir, Mr. Collin John Fernandez, Mr. Mohammad Ismail, Mr. Musaib Faizan Ahmed, Mr. Shams Mahmood and Mr. Vivin Pradeep have obtained Bachelors Degree in Mechanical Engineering from Manipal University Dubai Campus in 2012. All have worked on a research project funded by ASHRAE. They have participated in various technical events and have excellent academic record.