EXPERIMENTAL STUDY OF A DESICCANT INTEGRATED VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH MULTIPLE INLET PARAMETERS

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ABSTRACT

In Comparison of the performance between the conventional vapor compression system and liquid-desiccant assisted VCR cooling system, later system has proven to be an effective method to take care of latent load with lesser consumption of energy. The dehumidification process involving desiccant solution has become better and evolved. This paper highlights the experimental aspects of such a system and its performance. The experimental aspect of the present work investigates the hybridization of liquid desiccant system for dehumidification with conventional vapor compression refrigeration system for humid and hot climates. The latent heat load on the VCR system because of the dehumidification with is highly energy intensive.
The present works deals with experimentation performed on a hybrid system of smaller scale. The experiments are performed by optimizing the number of runs using central composite design technique with five variables as decision variables with the help of Minitab software. COP_{hybrid}, Humidity difference and Q_{deh} are taken as output parameters. Regression correlations are developed based on these experimental results.

1 INTRODUCTION

Energy scarcity is emerging as a global concern, along with environmental threat posed by the existing conventional cooling system; we need to design new energy-saving and environmentally friendly air-conditioning systems. Those needs are met satisfactorily by liquid-desiccant dehumidification. A desiccant material have been used for dehumidification for both industrial and agricultural purposes, such as controlling humidity in textile mills, and is now becoming used in the air-conditioning sector. VCR based cooling system takes both sensitive and latent load handling processes at the cost of higher energy, as evaporator has to be cooled to dew point temperature of air for dehumidification. This low temperature is higher than supply air temperature hence it is to be again reheated thereby energy is being wasted in excessive cooling and reheating. [1]. Desiccant dehumidification overcomes the above-mentioned problems in managing process air humidity by allowing maximum use of the surface vapor pressure difference to achieve moisture transfer between the liquid desiccant and the process air. Also it has few other advantages a) independent control over humidity resulting in size reduction of cooling machine and refrigerant fluid's mass which further reduces the agents responsible for ozone layer depletion and other pollutants. b) In industries like food and chemicals where preservation temperature needs to go lower there desiccant cooling is very effective than the conventional VCR system. c) Desiccant cooling system provides better indoor air quality as in conventional VCR there is condensation of water which may lead to microbial growth. d) Lower pressure drop of process air and any low grade energy source can be used if regeneration is being used to make the desiccant strong

again [2].

Conventional vapor compression refrigeration systems (VCR) have a majority share of electricity consumption in the summer season, especially in countries with tropical climate. According to the study by Brookings India, the rise in the total share of commercial electricity from the present 50 per cent to 75 per cent by 2030[3]. The same is expected that the market for household comfort will raise its share of power consumption by 2030 from the current 7 percent to 45 percent.

To reduce high grade energy consumption and discovering energy efficient system, researchers are continuously investigating alternate system and proposing system improvement to meet with the ultimate goals. Few researchers have studied liquid assisted VCR based cooling system. Khalil et al [4] has investigated a system with lithium chloride as desiccant combined with the conventional VCR system. They used R134a as refrigerant in VCR system. They achieved substantial improvement in cooling capacity from 0.75 to 1.75 TR. Yamaguchi et al [5] have carried out theoretical analysis as well as experimentation using lithium chloride as liquid desiccant with R407C as refrigerant. They concluded a COP of 2.7 and moisture removal from the air from 14 g.w.v./kg to 8.1 g.w.v./kg . Mohan et al [6] studied the effects of humidity and temperature of room on the system performance. They used lithium bromide with VCR system. Zhang et al [7] used condenser heat to regenerate the weak desiccant solution and found 35 % enhancement in performance of hybrid system than conventional VCR system. Mucke et al [8] investigated the performance of different configuration of the hybrid system and found that the highest efficient is one with a combination of indirect evaporator cooler and liquid desiccant which has used external heat source. For central European countries, the authors concluded that there is a saving in electrical power if condenser heat is used for desiccant regeneration. Jani et al [10] also concluded that desiccant usage is favorable in hot and humid condition as he achieved humidity ratio from 18 g/kg of dry air to 7.1 g/kg of dry air. Mansuriya et al [11] investigated the liquid desiccant based hybrid cooling system with three decision variables and found that liquid desiccant assisted VCR cooling system is promising solution for saving energy and improvising performance of conventional VCR system.

2. EXPERIMENTAL SETUP

The actual experiment setup is presented in Figure 1. The Experimental set up comprise of two sub system one is a conventional VCR system having 1 TR capacity with R134a and second liquid desiccant dehumifier system. VCR system consists of a sealed compressor (1 TR), a tube and fine type evaporator, an air-cooled (fine and tube type) condenser and capillary expansion tubing. Liquid desiccant dehumidifier system mainly comprises of liquid desiccant dehumidifier, which is packed-bed type and counter-flow type dehumidifier component. It is made of acrylic sheet .It is in rectangular shape having dimension 800 mm X 300 mm X 300 mm. The top cover of the dehumidifier is made open to allow the change of the spraying nozzle configuration, packing material and its height in future. The Poly vinyl Chloride (PVC) sheets are used as material for packing whose height can be kept according to design and having the same dimensioning as the dehumidifier. It is placed on a 4-leg support placed at the bottom of the dehumidifier.

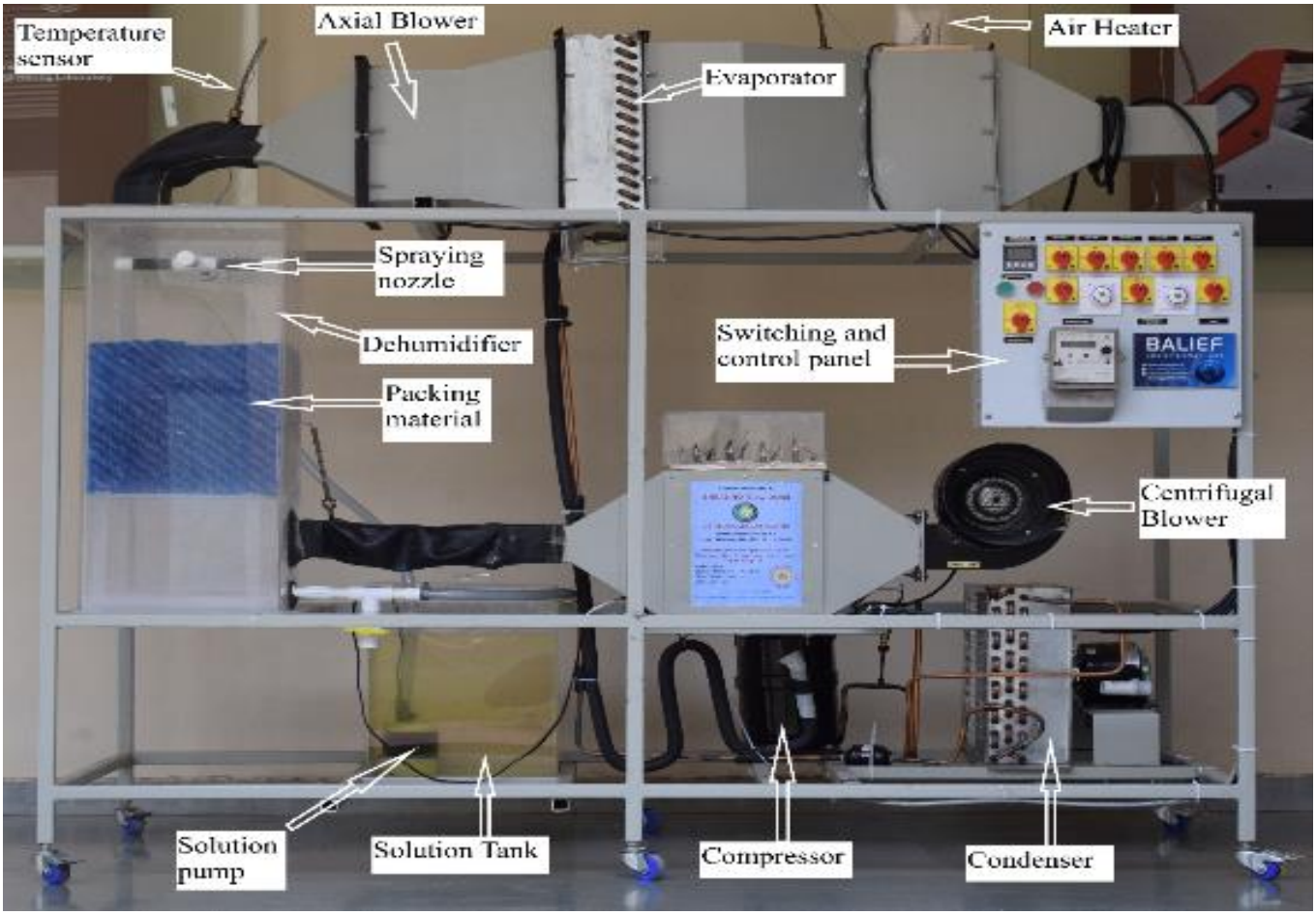


Figure 1: Experimental setup of hybrid system

Aqueous calcium chloride solution has been used as the desiccant. It would be pumped inside and then sprayed on the top of the dehumidifier by the help of a solution pump (40 W) via a control valve (to regulate the desiccant flow) and a flexible pipe. The desiccant solution after absorbing the moisture from the incoming air becomes weak and will go to the bottom of the dehumidifier and then will go to the collection tank from there it will be again pumped to the top of the humidifier at the nozzle to be sprayed again. The concentration of aqueous solution is kept 40 percent by weight which can be cross checked after preparing by hydrometer .The concentration can also be measured by knowing the temperature and the specific gravity and using the correlation developed by M. Conde [12]. The spray nozzle is of 0.5 inch diameter and has 24 holes in total, 6 in each arm and is made of PVC material. To create necessary air flow one axial fan at the beginning of evaporator section and other at starting the centrifugal fan is installed each having 140 W power rating. To create artificial hot condition 4 heaters each of 50 W is used and for creating desire humidity level, steamer is used at the entry of the section. Parameters of inlet condition and outlets are measured by keeping sensors in the appropriate positions. Air flow is measured by digital anemometer installed at the end of evaporator section.

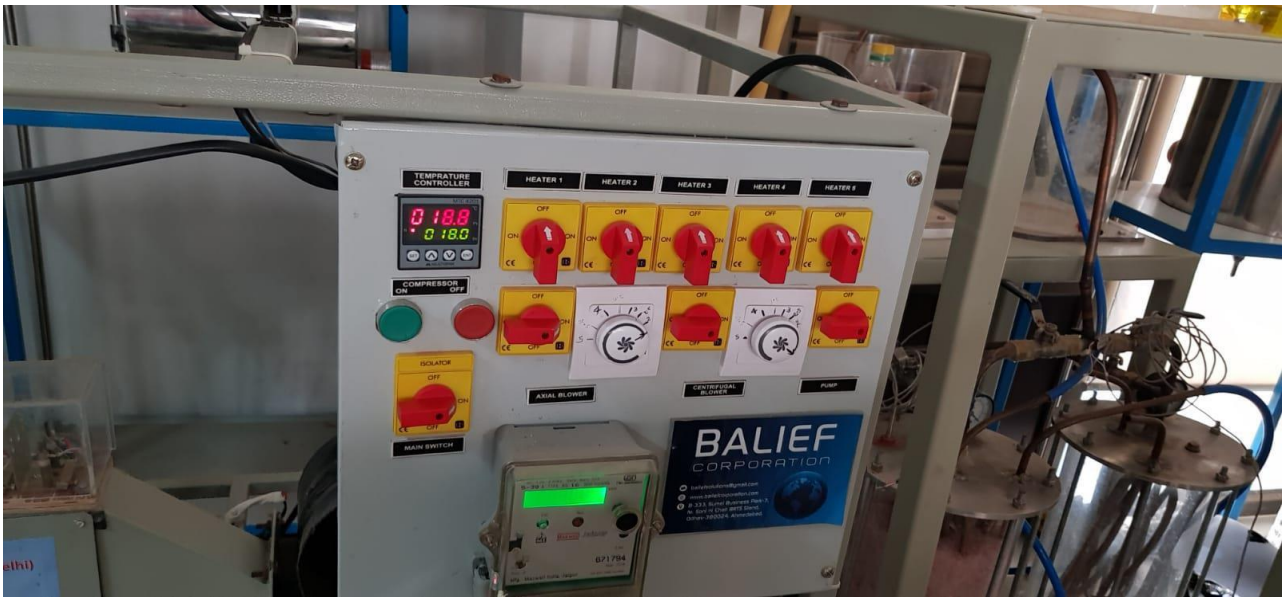


Figure 2: Electrical control panel of setup

3. DESIGN OF EXPERIMENT

Design of experiment (DOE) is systematic, structured method used to vary decision variables to measure their's influence on response variables. DOE helps to identify key decision variables, helps to understand interaction effect of them. It also reduces to time and cost of experimentation. It helps in optimizing the decision variables and also reduces the bias and noise. In present work, response surface method is employed to plan and execute the experiment.

Table 1: Specification of measuring devices

Instruments	Specifications
a) Temperature sensors	• PT-100 RTD • Measurement range (-5O degree to 200 degree Celsius) • Resolution .01 degree Celsius • Accuracy plus minus 0.1 degree celcius
b) Relative humidity sensor	• Multispan MTC -1101 • Range : 0% to 100% • Accuracy plus minus 1 percent
c) Hydrometer	• Specific gravity hydrometer • Range: 1 -2
d) Anemometer	• HTC-AVM-06 • Velocity of air: .8 to 30m/s • Accuracy :plus minus two percent of reading

3.1 RSM CCD Technique

A central composite design is an experimental design that is useful in response surface methodology to produce a second order (quadratic) model. Five parameters namely air mass flow rate, desiccant inlet temperature, desiccant inlet concentration, air inlet temperature and its relative humidity are taken as

decision variables in the present work. Their's upper, lower and medium bounds are shown in Table 3. Three parameters are taken as response variables, i.e., absorber heat load, COP of hybrid system, specific humidity difference across absorber.

Table 3: Levels of selected input parameters

	-1 (low)	0 (medium)	1 (high)
Air mass flow rate, m_air, kg/s	0.04	0.06	0.08
Desiccant inlet temperature ,T_d1, ^{0}C	27.0	30.0	32
Desiccant Inlet concentration X_1	0.38	0.39	0.41
Air inlet temperature, ^{0}C	35	37.5	40
Air inlet relative humidity, %	60	65	70

4. RESULT AND DISCUSSION

The experiment has been performed as per as CCD design, which gives 32 experimental runs with different combinations of five decision variables. The experiments are performed with values of decision variables as shown in Table 4. All sensors used for measurement were in good working condition and calibrated before experimentation. After ensuring steady state, observation has been recorded. Desiccant concentration was not changing much throughout the experiment which means our desiccant solution was not getting much weak during the dehumidification of the air , this is kind of advantage we have while using liquid desiccant over solid desiccant. Response parameters are derived by using well established expressions of it. The response variables are calculated using the measured parameters like air outlet RH and temperature, air temperature inlet to evaporator and room etc. The response parameters calculated for all the experimental runs are as presented in Table 5.

Table 4: Experiment runs as per CCD

Sr.	m_{air}, kg/s	$T_{d,I}$, ^0C	$x_{d,i}$	$T_{a,I}$, ^0C	$RH_{a,I}$,%
1	0.08	32	0.38	40	60
2	0.08	27	0.4	35	70
3	0.06	29.5	0.39	35	65
4	0.04	32	0.38	40	70
5	0.06	29.5	0.39	37.5	65
6	0.06	29.5	0.39	40	65
7	0.06	29.5	0.39	37.5	65
8	0.06	29.5	0.4	37.5	65
9	0.04	29.5	0.39	37.5	65
10	0.04	27	0.4	40	70
11	0.06	32	0.39	37.5	65
12	0.04	27	0.4	35	60
13	0.08	29.5	0.39	37.5	65
14	0.08	27	0.38	40	70
15	0.06	29.5	0.38	37.5	65
16	0.06	29.5	0.39	37.5	65
17	0.08	32	0.4	35	60
18	0.06	29.5	0.39	37.5	65
19	0.04	27	0.38	35	70
20	0.04	27	0.38	40	60
21	0.04	32	0.38	35	60
22	0.08	32	0.38	35	70
23	0.06	29.5	0.39	37.5	70
24	0.08	32	0.4	40	70
25	0.04	32	0.4	35	70
26	0.08	27	0.38	35	60
27	0.06	29.5	0.39	37.5	60
28	0.04	32	0.4	40	60
29	0.06	29.5	0.39	37.5	65
30	0.06	27	0.39	37.5	65
31	0.08	27	0.4	40	60
32	0.06	29.5	0.39	37.5	65

Table 5: Response parameters

Sr.	Δω, gms/kg d.a.	Q_deh, kJ/kg	COP_hybrid	Sr.	Δω, gms/kg d.a.	Q_deh, kJ/kg	COP_hybrid
1	6.6	14.8	2.4	17	4	8.8	1.49
2	5	11.6	1.44	18	5.2	11.6	1.88
3	5	11.6	1.55	19	4	8.8	1.44
4	6.6	14.8	2.31	20	6.6	14.8	2.23
5	5.8	13.1	1.82	21	5	11.6	1.55
6	6.6	14.8	2.4	22	5	11.6	1.5
7	5.8	13.1	1.88	23	5.2	11.6	1.82
8	5.8	13.1	1.82	24	6.6	14.8	2.4
9	4.6	10.1	1.81	25	5	11.6	1.55
10	5.3	11.4	2.39	26	4	8.8	1.55
11	5.8	13.1	1.88	27	4.6	10.3	1.88
12	6	14.4	1.56	28	5.3	11.4	2.31
13	6.3	14.67	1.82	29	6.3	14.67	1.95
14	6.6	14.8	2.4	30	4	8.46	1.81
15	5.2	11.61	1.95	31	5.3	11.4	2.31
16	5.8	13.1	1.95	32	6.3	14.6	1.95

5. CONCLUSION

This experimentation helps us to understand the working of small-scale hybrid cooling system involving combination of the two technologies of VCR system and liquid desiccant dehumidification. Central composite design (CCD) was used to design the system along with the added advantage of optimizing the number of runs. The experiments are designed with MINITAB statistical tool and for five factors, three levels and three responses. The results obtained for all the responses reveals maximum responses yield at relatively lower air flow rate, lower inlet temperature of the desiccant and higher inlet concentration of the desiccant for considered ranges of the decision variables. Also it reveals that the inlet factors of air temperature and inlet humidity ratio have a little significant effect on the output parameters.

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