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Evaporative Cooling System for Air Conditioning

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Abstract: Vapour compression systems are most widely used Air-conditioning and Food Refrigerating systems. Their drawbacks include large energy consumption due to the compressor and harming the atmosphere directly (due to leak of refrigerant gases) or indirectly (electricity to power these systems comes largely from thermal power plants). Evaporative cooling systems are an alternative to the vapour compression systems. It is a relatively old technology that is slowly gaining popularity thanks to awareness among the general population about their own impact on the environment. Evaporative cooling systems are eco-friendly because they work on the principle of evaporation of water to achieve cooling. But they are effective in dry climate only. Thus to tackle the cooling loads in humid climate, we can make use of Desiccant technology. Liquid desiccants are solutions of salts and water that dehumidify and cool the air by absorbing moisture from moist air. Earlier desiccant packed beds or wheels were used but liquid desiccants have a higher moisture absorption capacity. A cooling system is designed and fabricated that can achieve either dehumidification or humidification and cooling based upon concentration of salt used into the water.

Keywords: Evaporative Cooling System, Liquid Desiccant, Dehumidification, Calcium chloride

Aim: To design and manufacture an evaporative cooling system while implementing desiccant technology in minimum time with minimum cost.

I. INTRODUCTION

Traditional vapour compression systems (VCS) employing vapour compression cycle have been used for air-conditioning & refrigeration in both industrial and residential applications. Thus, these systems are quite popular and well known. But some limitations of the VCS technology are that the refrigerant gases used are harmful for the environment and also these systems have high energy consumption in the form of electricity. An alternative to these systems are the evaporative cooling systems (ECS). These systems achieve cooling effect through evaporation of water. The ECS can be categorized into direct contact and indirect contact devices. Since the working fluid is water, there are no harmful by-products of this system. Major advantage of ECS is that it blows fresh air into the desired location instead of recirculating same air like VCS. Only a fan or blower is required to circulate cool air. Also, pumping device is required to circulate water throughout the circuit. Hence, ECS have comparatively less electricity consumption than VCS. Despite these advantages, the ECS can be employed only in environments having less humidity. This is because ECS work on the principle of evaporation of water. As warm air comes in contact with cool water, the water at the contact evaporates.

The energy for vaporization comes from air in the form of heat, thus reducing air temperature. This type of cooling becomes difficult as humidity of environment increases. To overcome this drawback of the ECS, desiccant technology will be utilized. Desiccants are of two types – solid desiccants (salt beds) and liquid desiccants (salt water solutions).

Desiccants are hygroscopic in nature & hence they absorb moisture from the air by condensation of water vapour due to vapour pressure difference. Again the energy for condensation comes from warm and moist air in the form of heat energy and decreases the air temperature. Most of the researchers have used adiabatic contacting devices, but by cooling the LD (Liquid Desiccant) during the process of dehumidification, it will retain the water vapour pressure, hence allowing high concentration and low flow rate of LD [1]. It becomes weak by absorbing moisture from the surrounding hence it is necessary to regenerate the LD which is done by LD regenerator [2]. Two stage regeneration of LD can be done to improve the energy efficiency of the system and hence we can achieve techno-economical superiority [3]. Thus, using LD in direct contacting device can achieve cooling effect in an eco-friendly way for humid climates as well.

Fig.1 shows top view of a rotating disk type evaporative cooling system in which several disk are mounted on a shaft which is driven by a motor. The hot air enters at inlet end, and after cooling and dehumidification, exits from the opposite outlet end.

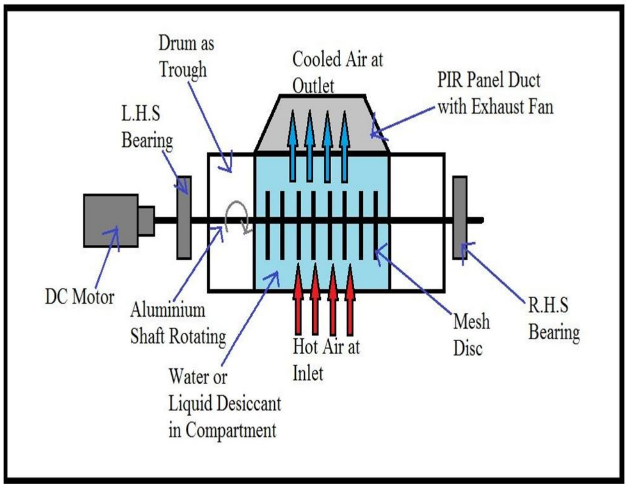

Fig. 1: schematic diagram of the setup

II. SYSTEM COMPONENTS

A. *Trough*

We can use water trough made up of various materials viz. Steel drum, PVC pipe, HDPE drum. Among these the HDPE drum was the least reactive to the liquid desiccant. Also, while considering the availability and the cost, it was the best choice.

B. *Desiccant*

While considering the properties of various desiccants, availability, economical factors, storage, and reactivity of the LD with the other components, Calcium Chloride ($CaCl_2$) solution was selected as the LD.

C. *Mesh disc*

The discs were required to form an appropriate film on them. According to the calculations made the basic dimensions of the mesh disc were decided and the number of discs to be mounted was decided as 30 nos.

Fig.2 shows the mesh disc with square slot and Fig .3 shows film formation on mesh disc while actual working.

Diameter of each disc = 250 mm = 25 cm

Thickness of each disc = 0.75 mm

Total area of disc = (Π *25*25)/4

= 490.625 cm ^{2}

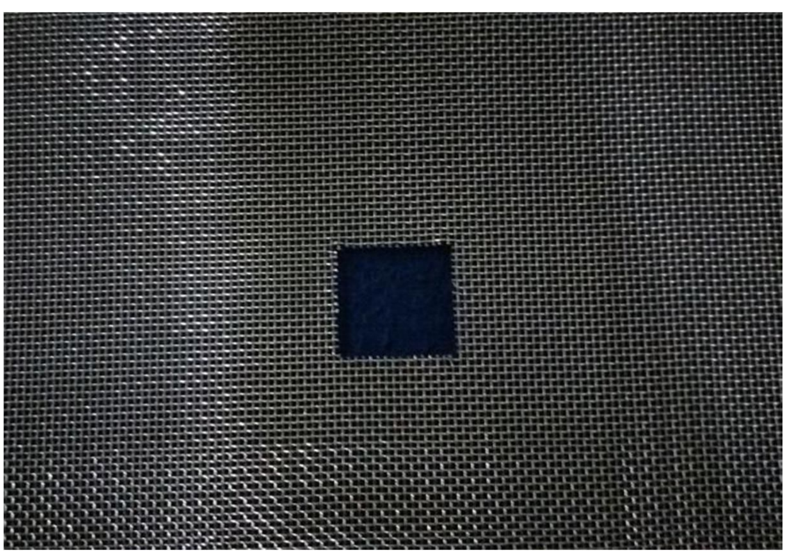

Fig. 2: Mesh disc with square slot


Fig 3.: Film formation on the mesh disc

D. *Shaft*

The shaft was subjected to torsional and bending stress. Also, it was in continuous contact with the LD solution. Hence it was necessary to select the material according to these parameters. So an Aluminum Alloy 6061 shaft is selected. The dimensions of the shaft were designed according to the dimensions of the Trough. The shaft was supported on both ends by ball bearings. The loads acting on the shaft are the load due to self-weight of shaft and weight of mesh discs. The cross section of the shaft was kept square so that the disc and shaft would lock. Also, the shaft was kept hollow to minimize the weight.

E. *PIR panel*

Duct was required to provide the cool air at the outlet. The galvanized iron ducts and aluminum ducts had their disadvantages in thermal conductivity hence we decide to use smart PIR panels which had better insulations and lowest thermal conductivity(0.021 W/mK).The dimensions of the panel was decided according to the cooling desired and the exhaust fan dimensions.
Fig. 4 Shows the CAD model of the actual fabricated PIR panel.

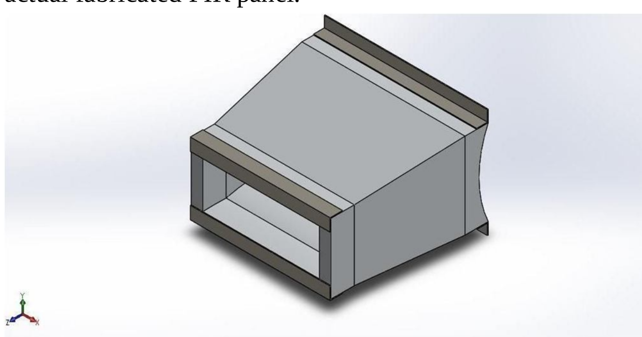
Fig 4.:CAD model of fabricated Smart PIR panel

F. *Motor and Exhaust Fan*

The shaft must run at low RPM in range of 10-30 RPM to avoid the splashing of the LD solution in the trough. A geared motor with 30 rpm was selected with no load torque output as 18 kg-cm. The exhaust fan was decided upon the temperature difference desired. Two exhaust fans of 80 cfm were installed at the outlet so that cooled air is exhausted through the PIR panel with certain temperature drop.

Total Mass moment of inertia of the system (I)

= (3.45e-5) + (0.01374)

= 0.0137745 Kg-m ^{2}

Torque for starting and rotating = Rotation torque + Starting Torque

Rotation Torque = I * a

Here, I = Total moment of inertia of rotating components

= 0.0137745 Kg-m ^{2}

a = Angular acceleration of the system, considering rotation speed of 15rpm & time to accelerate is 1 second from zero to 15rpm (1.571 rad/s).

Thus, Rotation Torque = I * a = 0.0137745 * 1.571

= 0.02164 N-m

The square shaft is to be supported by bearings. To facilitate this, we use two small shafts that are square on one end and circular on the other end. This helps transfer rotation from square to circular cross-section. Since maximum cross-section dimensions of the small shafts are 14 mm x 14 mm, we consider a bearing with inner bore of 10 mm for calculating starting torque.

Starting Torque = $f * (M_d + M_s) * g * R$

Here, f = friction coefficient of the bearing = 0.3 (assume) R = Radius of inner bore of bearing = 10mm = 0.01m

Starting Torque = 0.3 * {(30 * 0.058) + (0.371)} * 9.81 * 0.01

Thus, Total Torque for Rotation and starting (T)

= 0.02164 + 0.52

= 0.54164 N-m

Thus, Equivalent Torque = $\sqrt{\{BM^2_{Max} + T^2\}}$

$= \sqrt{\{3.41^2 + 0.54164^2\}}$

= 3.453 N-m

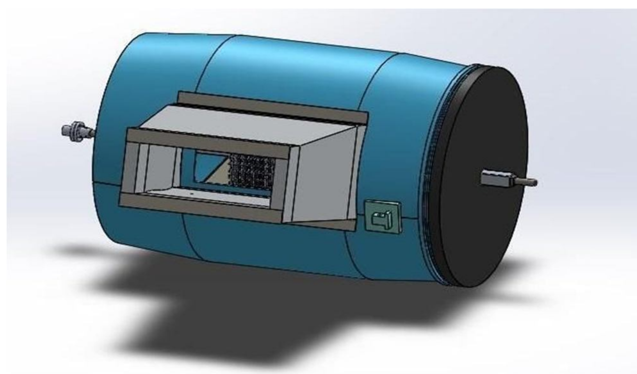

Fig.5: CAD model of the setup

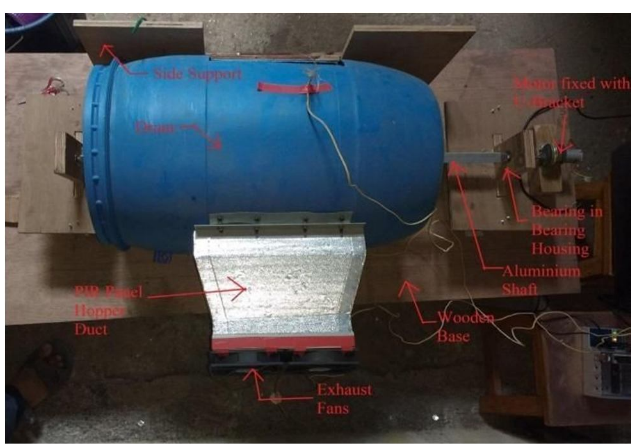

Fig.6:Top view of the actual working setup

III. RESULTS AND DISCUSSIONS

Using 16% $CaCl_2$ by mass at 32 ^{0}C temperature, Air DBT = 37 ^{0}C and WBT = 26.5 ^{0}C, 44.27% RH, running the shaft at 15rpm and running the exhaust fans:

Table 1: Set-1 Readings

Sr. No.	T Inlet (^oC)	T Outlet (^oC)	T Drop (^oC)	Time (Minutes)
1	36.06	33.85	2.21	2
2	36.15	33.73	2.42	4
3	36.23	33.36	2.87	6
4	36.08	33.65	2.43	8
5	36.17	33.78	2.39	10

A. T- Temperature

For set-1 readings, the relative humidity was 44.27% and hence the liquid desiccant at 16% concentration (by mass) was able to dehumidify and cool the air.

Now by using water at 30 ^{o} C temperature, Air DBT = 36 ^{O} C and WBT = 29 ^{o} C, 59.76% RH, running the shaft at 15rpm and running the exhaust fans:

Table 2 : Set-2 Readings

Sr. No.	T inlet (^oC)	T outlet (^oC)	T Drop (^oC)	Time (Minutes)
1	37.61	36.68	0.93	2
2	37.25	36.65	0.6	4
3	37.41	36.66	0.75	6
4	37.09	36.81	0.28	8
5	37.02	36.67	0.35	10

Next set of readings were taken by using water at 30 ^{o} C temperature, Air DBT = 36 ^{o} C and WBT = 29 ^{o} C, 59.76% RH, but by keeping the shaft stationary after creating water film and running the exhaust fans:

Table 3: Set-3 Readings

Sr. No.	T Inlet (^oC)	T Outlet (^oC)	T Drop (^oC)	Time (Seconds)
1	37.74	36.22	1.52	30
2	37.23	36.17	1.06	60
3	37.78	36.73	1.05	90
4	37.64	35.76	1.88	120
5	37.67	35.87	1.8	150
6	37.63	35.95	1.68	180
7	37.71	36.05	1.66	210
8	37.66	35.78	1.88	240
9	37.57	36.44	1.13	270
10	37.63	36.45	1.18	300

For set-2 and set-3 readings, since the relative humidity was 59.76% and the water being at 30 ^{o} C, evaporation of water film was comparatively less and hence cooling effect was also less. Comparing set-2 and set-3 readings, since the water film temperature is same, there should be little to no difference between the two outlet temperatures. The reason is that change in relative velocity between water film (on the disc) and air is very low when comparing stationary film and film rotating at 15rpm. But there is a significant difference between the two. The temperature drop in set-3 is greater than temperature drop in set-2 due to increase in contact time between the water and flowing air.

IV. CONCLUSIONS AND FUTURE WORK

Hence we can conclude that the Evaporative Cooling System fabricated and tested would be cost effective and the performance was optimum. The power consumption of the entire system was as low as 13W and hence the actual COP was high in the range of 10-15.With the use of desiccant the humidity as well as the temperature can be kept within the range of human comfort. We can achieve more temperature difference by using water or liquid desiccant having lower temperature (and thus lower vapour pressure). The desiccant used was selected by keeping the cost of the system and the short term use. The life of the unit can be increased by using inhibitors to restrict corrosion of the mesh disc and the other metal component in the system.

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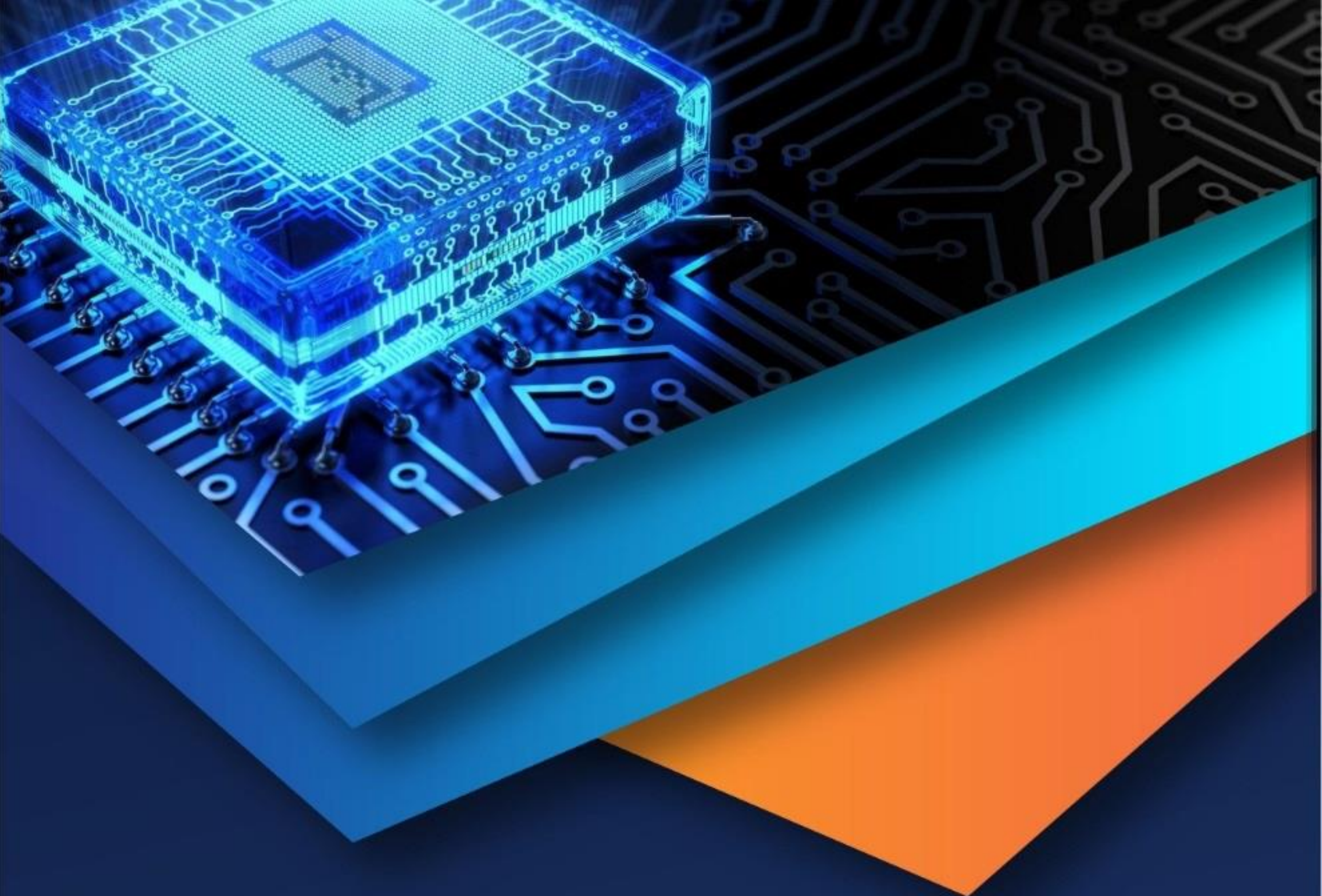

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