Novel Setup for Water Harvesting Technique

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Abstract **- Water extraction from thin air can be a solution for solving water scarcity problems with regions having high humidity. In this paper, water harvesting from thin air is done using a novel combination of Peltier modules with chemically treated aluminium plates. The Al plate was treated in such a way that the plates became slippery. These plates were cut in such a manner that it improves nucleation to a faster rate.**
Thermally insulated model (volume 40L) with 24 CFM (cubic feet per minute) for the input of humid air with directional heat sink was used (see image). Total power consumption of the setup was 249W. The minimum temperature achieved on the cold side of the Peltier module was 6.4 ºC measured using LM-35 sensor. Humidity was also measured using the DHT-11 sensor. This model was tested in two different regions - Roorkee (IIT Roorkee) and Pune (IISER Pune) during the month of June-July. The final water collection at Pune was more (50 ml in 3h, relative humidity ~ 70%) than Roorkee due to the fact that Pune has more relative humidity. Thus, this study can definitely help to create an actual working prototype which can be deployed in the market.

Keywords - *Water extraction, Water harvesting. Relative humidity, Peltier module*

1. Introduction

Since the beginning of 20th-century, water scarcity has been a major issue all over the world, especially in those inhabited deserts and arid regions. In those arid regions having a shortage of water resources and rainfall are also scarce most of the creatures rely on the humid air as their major source of water. One such region is the Namib Desert, here creature relies on the water from fog and humid air.
Many studies had been conducted in the past to study climatic condition and water collection from humid air in this r**egion**[1-4]. The Nambi desert beetle Stenocara, cactus and spider silk have promoted a lot of fog harvesting **devices**[5]**.** Among these creatures, the Stenocara beetle is the one who uses humid air to extract water. The extracted drop is directed to its mouth as its carapace has a hydrophobic surface with a random pattern of hydrop[hillic bumps. this combination is really effective as hydrophilic bumps enhance nucleation and accelerate water harvesting rate while the hydrophobic surface accelerates water drainage so that concentration gradient remains constant. Many attempts were also made to mimic spinelike water collecting materials[5,7], but they are complicated to manufacture and also did not have effective drainage capability.
The water-harvesting involves 3 steps:-

1. Water Capture: This process involves capturing of tiny droplets over the water collecting surface.
2. Water Supply: It involves coalescence between water droplets water
3. Water Drainage: Process of drainage of harvested water.

Among these water capture and drainage are mostly affected by surface chemistry while water supply is mostly related to viscous forces in the air which carries the condensed water with it. Very less attention has been given to water supply in past researches.
According to dimensions, water harvesting surfaces can be divided into 1D, 2D and 3D surfaces. among theseAmong 3D water-harvesting surfaces are rarely fabricated, while 2D surfaces and 1D wires have been widely used for water harvesting. Leaf of pitaya plant was covered by the 1-D thorns, which was efficient in water harvesting but they were not efficient in the water supply(Fig.1(a) and Fig.1 (b) show a glimpse of pitaya plant covered with thorns).[5] 2-D surfaces can be made efficient in all of the steps of water harvesting by keeping them in a thermally insulated enclosure.

The water harvesting platforms had shown great results in the past but most of them require a low-temperature environment and in this literature combination of the existing water harvesting technology and temperature drop out has been tested which have shown favourable results.

Fig.1(a) Optical image of pitaya 1(b) Pitaya plant leaves covered with thorns

2. Materials and methods

2.1 Materials: NaCl and H2C2O4(of analytical grade Conc.: 0.1mol L^{-1} and 0.3mol L^{-1} respectively), Fluoroalkylsilane [FAS, $C_8F_{13}H_4Si(OCH_2CH_3)_3$] (analytical grade), Silicone Oil. Peltier modules(module no.12076 60W 8A), Teflon Coated Acrylic sheets(3mm thickness, doubly layer coated), Thermal paste, Heat Sink with heat pipe(tube material: Copper, with water evaporative cooling) and cooling fan(input volt-4-5V), Rectangular heat sink, Power Supply Unit(Input: 220-240V AC, Output Voltage: 11.1-12.8V DC, Current rating-5-12A) Sensors for data collection used were DHT 11(Analog output, input volt.: 3.5-5.5V), LM35 thermistor. Air intake fan(24 CFM), Aluminium sheet(Alloy grade: 1060) of thickness 1mm procured from Royal metals Ltd.

2.2 Experimental Methods:-

2.2.1. Slippery surface fabrication

Aluminium plates were chemically etched using (anode-aluminium plate; cathode-copper plate) in NaCl (0.1mol L^{-1}) neutral electrolyte at the current density of 0.5A-cm^{-2} to make the surface superhydrophobic in nature. The etched plates were treated with anodic oxidation in oxalic acid (0.3 mol L^{-1}). The anodized surfaces were immersed in a solution of 1% Fluroalkylsilane for 40min and then dried at 100 deg. C for 20min. At the end silicone oil was applied to the treated surface and then inclined at 45 deg. for 2h to form slippery surface.

2.2.2. Thermally Insulated System Fabrication

Teflon coated acrylic sheets of surface area 1.75ft * 1ft were assembled to make a thermally insulated rectangular enclosure. Teflon coated surface provides a hydrophobic surface to prevent sticking of droplets on walls of setup. Joints of setup were made with 3d-printed trusses (to reduce weight). PLA (polylactic acid) was used for 3d printing as it is a food-grade material. Intake fans were installed at 4 sidewalls on the upper-mid side for the direct contact of air to condensation surfaces. The top sheet(ceiling) of setup provided with 4 slots, for Peltier module installation, made using a CO_2 laser cutting machine. Peltier modules were installed in the slot with cold side facing the bottom of the setup and hot side facing upward exposed to the atmosphere.

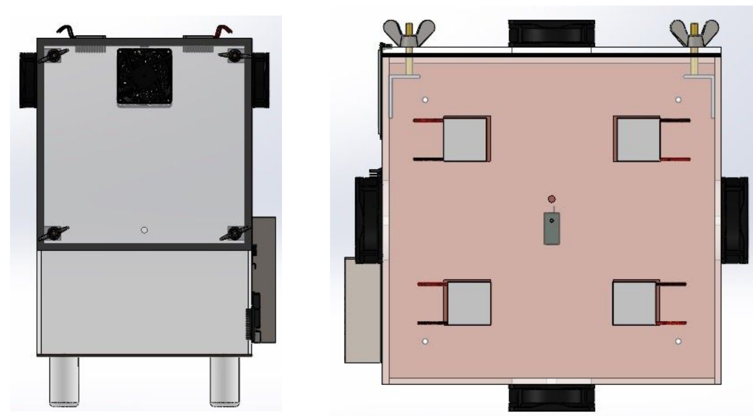

Fig.2(a) Front view Fig.2(b) Top view

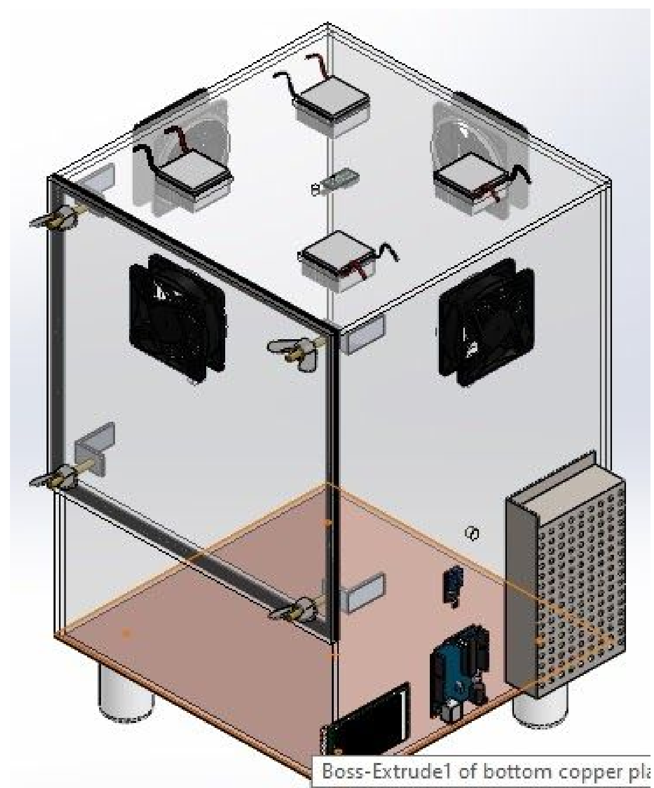

Fig.2(c)Isometric View

I glimpse of the setup has been shown in the **Fig.2(a,b,c)**.

To increase the heat transfer area, on the cold side, aluminium oxide heatsinks were installed with high absorptivity and less emissivity to reduce the rate of temp.

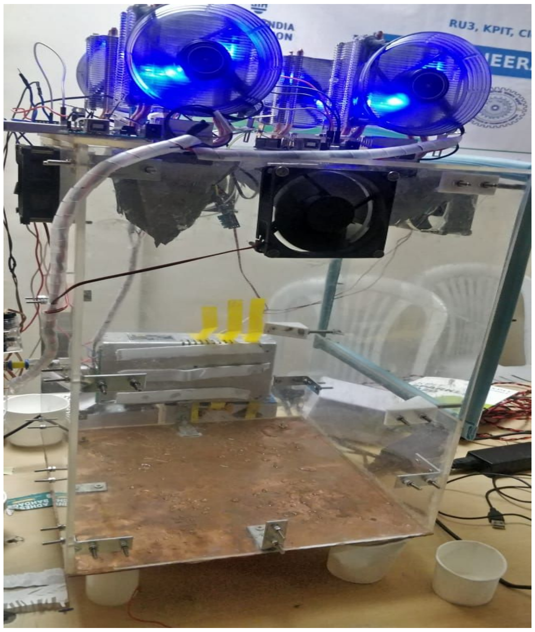

Fig2(d). Fabricated Model

rise. On the hot side of the Peltier modules, directional heatsink equipped with copper heat pipes were installed using thermal paste(Thermal paste helps in sticking two faces for heat transfer without any micro air gap between them). Heat flow inside the directional heat sinks is shown in **Fig.3(a)[6] and Fig. 3(b)**

Fabricated aluminium slippery sheets were cut in rectangular

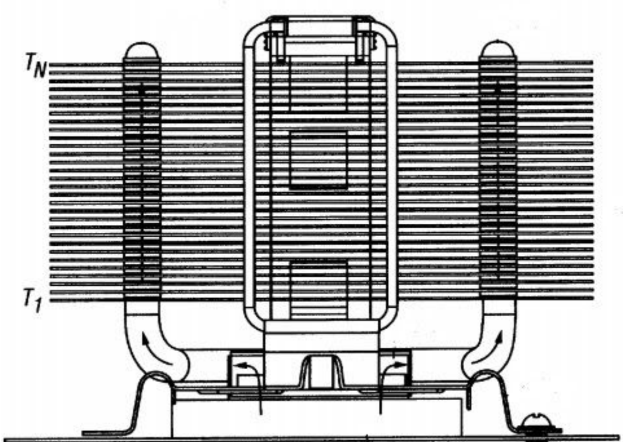

Fig.3(a) Heat flow in directional heat sink.

Fig.3(a)Heat flow in Directional heat ink.

of 7cm*10cm and installed in the gaps between the heat sinks on the cold side. To make contact between the heat

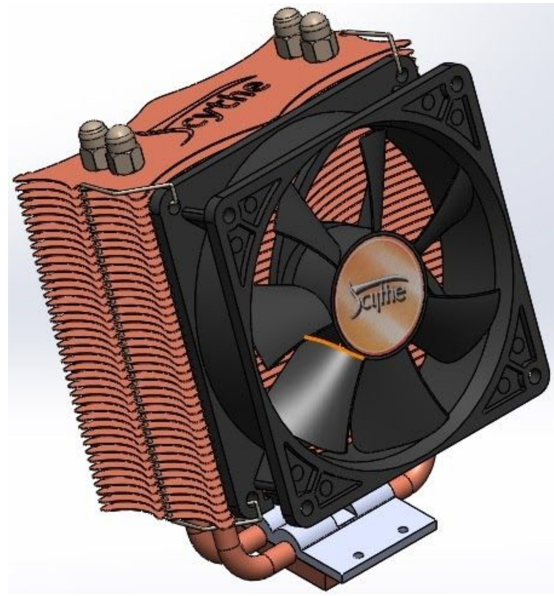

Fig.3(b) Directional heat sink assembly with Cooling fan.

sink and plate 'thermal resistance-free', surfaces were coated with thermal paste. Several topographical changes with etched aluminium sheets were tested :

- Rectangular sheets with sharp edges of surface area 7cm*10cm.
- Triangular sheets with 7cm base and 10cm height.
- Triangular sheets with sharp spines along the edges.

At last, to prevent any thermal and air losses from corners and edges of setup thermal resistive adhesive was applied along the edges.

3. Results and discussion

3.1 . Aluminium treatment

After electrochemical etching, the Al surface was covered by the micron-sized stepped structure, as shown in Fig. 4(a). After anodic oxidation, generation of nano holes in plate was formed. The blackish part of the aluminium plate is the one where complete treatment is not done (i.e. no FAS modification). Hence, as clear from following image that water collection take place at treated part of aluminum plate.

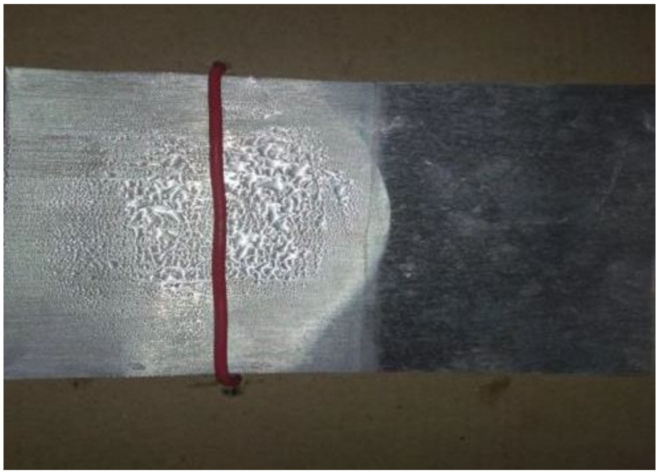

Fig 4.a) The treated and non treated aluminium surface

The second image (Fig .4 b)) shows water collection on the aluminium plate with nucleated spikes on it. It is clearly visible that the water droplets formation took place on plates. Since the plate was cut in the shape of leaf structure, the nucleation rate increased. Due to the slippery nature of plates, the droplets fall down quickly.

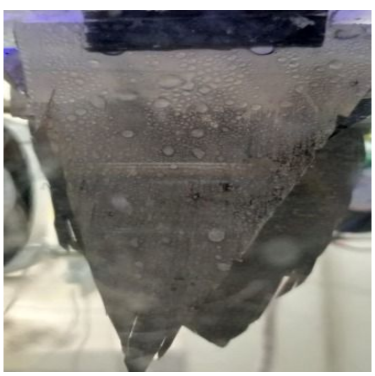

Fig.4b) Treated aluminium plates attached with Peltier module

3.2 Water collection

The data of water collection was taken at two different humidity levels - at Roorkee and Pune. The readings were taken in the month of June July when the humidity in the air is at its highest level. The relative humidity at Roorkee was 40% while at Pune was 70%. Humidity was measured using DHT-11. The temperature across the peltier module was measured using LM 35. The minimum temperature achieved was 6.4-degree celsius.

Total water collection at Pune was 50ml in 3 hours. At Roorkee, 5-10 ml of water collection takes in 3 hours. The electricity consumption was measured using a multimeter. A total 250W consumption of electricity was observed.

3.3 Modelling:

The whole process was modelled in MATLAB programming. The assumptions were as follows:

- Thermally insulated setup from surrounding
- Humidity remains same at all points inside setup

The amount of water collected is as follows:

w = (xi*ni -ni*xo)/5

where

w= amount of water collected (ml/min)

xi=amount of water in ml per kg of dry air (inlet)

ni = dry air flow rate (kg/min)

xo = maximum amount of water in ml per kg of dry air assuming that relative humidity is 100% at lowest Peltier module temperature.

⅕ factor is used since plate length is equal to ⅕ of the total length of setup.

The error with actual water collection and theoretical water collection was very large and hence, a suitable measure to change code is necessary.

4. Conclusion

In observations of the results attained, it can be concluded that surface-treated aluminium sheets are effective in enhancing the rate of nucleation. Directional flow of air over the surfaces was also helpful in the water supply step of water harvesting technique. Peltier modules were also effective in creating a low-temperature environment to enhance condensation. More study can be carried out for optimizing the volume of the air intake, the surface area of Al sheets to maximize water extraction and minimize specific energy consumptions.

References

[1] Hachfeld, B. and Jürgens, N., 2000. Climate patterns and their impact on the vegetation in a fog driven desert: the Central Namib Desert in Namibia. *Phytocoenologia*, *30*(3/4), pp.567-589.

[2] Pietruszka, R.D. and Seely, M.K., 1985. Predictability of two moisture sources in the Namib Desert. *South African journal of science*.

[3] Cereceda, P., Larrain, H., Osses, P., Farías, M. and Egaña, I., 2008. The spatial and temporal variability of fog and its relation to fog

oases in the Atacama Desert, Chile. *Atmospheric Research*, *87*(3-4), pp.312-323.

[4] Olivier, J., 2002. Fog-water harvesting along the West Coast of South Africa: A feasibility study. *Water Sa*, *28*(4), pp.349-360.

[5] Zhong, L., Zhang, R., Li, J., Guo, Z. and Zeng, H., 2018. Efficient fog harvesting based on 1D copper wire inspired by the plant pitaya. *Langmuir*, *34*(50), pp.15259-15267.

[6] Lofland, S.J. and Chesser, J.B., Intel Corp, 2003. *Heat sink with heat pipes and fan*. U.S. Patent 6,625,021..

[7] Heng, X., Xiang, M., Lu, Z. and Luo, C., 2014. Branched ZnO wire structures for water collection inspired by cacti. *ACS applied materials & interfaces*, *6*(11), pp.8032-8041.