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Study of Condensation on PDMS Substrates for Enhanced Solar Still

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Abstract: **Condensation surfaces are found in many applications from solar stills to phase change heat exchangers, solar condensers etc. In all these applications, it is important to increase the condensation efficiency by engineering the surface which yields better condensation properties that are suitable for targeted needs. In the current project, we envisage such an effort where metal elastomeric composite substrates are employed to increase condensation efficiency.**

We use Polydimethylsiloxane (PDMS) as a choice of elastomer and Aluminum particulates as the choice of the metallic inclusions. Write after preparing the substrates of different portions of metallic particulate inclusions and condensations, tests are carried out on each substrate separately. Here we prepare a few substrates by varying the Aluminium metallic particle mass fraction over five decades from 10^{-6} to 10^{-8}. The substrates thus obtained are used in condensation tests. From the measurements, a dew condensation rate was calculated. The tests were repeated four to five times to ensure repeatability of the measurements. Care was also taken to ensure that all the measurements were obtained in the same atmosphere.

The dew condensation rate was studied by varying the Aluminium mass fraction in the substrate. A non-monotonic behavior was observed wherein high condensation rates were obtained for an Aluminium mass fraction of approximately $5*10^{-4}$ g. For all other mass fractions, the condensation rates are less than this above condition. Therefore, it can be concluded that this is an optional mass fraction for which dew condensation efficiency was the highest

Index Terms: **Elastomer, PDMS, Condensation, Mass fraction, Substrates, Dew**

I. Introduction

It is needless to mention that water, a compound of Hydrogen and Oxygen is a precious natural gift, which is very essential for survival of humankind including animals. Nowadays pure water is a rare substance. There are so many ways to produce potable water for example water purifiers, water treatment in plants like sedimentation, filtration etc. However, all these processes need some external power supply and not everybody can afford those systems. In some remote areas there is no availability of electrical power source also. One of the alternatives to get potable water is by using solar stills. Even though production rates are low it is viable because of low initial cost and it does not need electricity. Solar still is a low-tech way of distilling water with the help of heat of the Sun, to be precise the heat and humidity of the soil, and relative cool of plastic.[1]

Further, dew can be collected from the atmosphere using hydrophobic substrates and used for drinking purposes. Dew is a commonly occurring natural phenomenon where the humid air condenses on a substrate and transforms into liquid water. Colleting of water from atmosphere which is in the form of Dew is not a new idea, some experiments have been done and some are going on. The main problem in harvesting Dew water from the atmosphere is setting up of the process is difficult and not effective; sometimes it is expensive, considering the output obtained.

A. Formation of dew

Dew is a natural phenomenon where humid air condenses on a substrate and finally transforms into liquid water [2]. Dew can be a potential source of water. Dew is a surface phenomenon. In some cases, dew is an unfavorable phenomenon. On plant leaves it develops spores, mainly fungus spores, which are undesirable for the process of photosynthesis. It lowers the transmission of light by more than 50% when it forms on greenhouse shields and affects the yield of agricultural production [3]. Studying and controlling of Dew is found in medicine for sterilization processes, agriculture field and in Nano-electronics to know and control vapor decompositions.

The formation of dew is essentially a problem of phase transition, the presence of other gases like nitrogen or air do not affect fundamental problems of condensation. The surface properties of the substrate can modify the conditions of formation of liquid phase. With desired geometrical conditions of the substrates the growth of the dew is controlled [4]. Another important thing is wetting properties of the substrate. The wetting properties decide whether the condensation is either drop wise or film wise

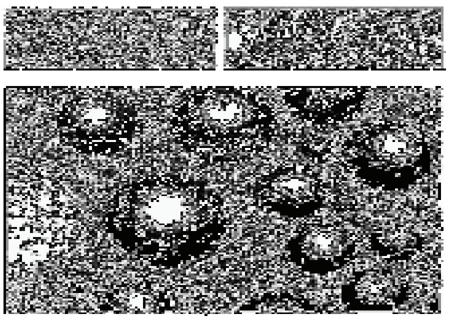

Figure 1. Self-similar growth of a pattern of droplets condensing on hydrophobic glass.

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The pattern at t=1s (a) after condensation started, is equivalent to the one at t=6s (b). In (c)att=25s, new families of droplets have nucleated between the initial drops. Source: D. Beysens / C.R. Physique 7 (2006) 1082-1100.

There are some other cases where the growth of the drops is favorable. The key role of the growth of the drops is its perimeter. If the temperature gradients are higher, accommodation of molecules of water is also high. The temperature gradients due to thermal release of energy at the substrate surface are parallel to the liquid-vapor interface leading to flows of Marangoni effects [5]. This will increase the growth pattern. The very small drops of critical radii coalesce with each other until they form a stable drop. This leads to distributions of drops on the substrate at a later stage. On the substrate, continuous nucleation and evaporation leads to surface diffusion that feeds drop at its perimeter [6].

II. Experiments

The substrates were prepared by mixing prescribed amounts (by mass) of Aluminium powder in a known amount of PDMS, while the elastomer was in the pre-cured state. Then the liquid was poured on a flat surface and allowed to cure for some time. The experiments consist of preparation of hydrophobic surface using Sylgard 184: Silicone elastomer with very little amounts of Aluminum metal powder inclusions. Quantitatively calculate the condensation rate on those surfaces and finally calculate the humidity in the atmosphere. The condensation tests involved measuring the true weights using microbalance. We then place the substrates on a block of ice for definite time and allow the dew to condense on the top surface of the substrate by lowering of the substrate temperature. Then the masses of the substrates are measured before and after placing on the ice block. This process is repeated, and all the dry weights and wet weights are noted down for further comparisons. All these experiments are conducted in same environmental conditions.

A. Hydrophobic Surfaces

Preparation of Surfaces : The super hydrophobic surfaces are created by using SYLGARD 184: Silicone elastomer, which is supplied as two-part liquid component kit comprising of Part A/Part B (Lot-matched base/Curing agent) to be mixed in a 10:1 ratio by weight or volume. The mixing can be done either manually or automatically by any mixing equipment and the final mixture is dispensed to form a desired shape of substrate. When the two liquid components are mixed thoroughly, the mixture cures to be a flexible elastomer.

When ten parts of base material mixed to one part of curing agent and are thoroughly mixed and agitate gently to reduce the amount of air introduced. Allow the mixture to set for 30 minutes before using. This may be adequate for removal of the air introduced during the mixing process. For best curing results, glassware and glass or metal stirring implements are used. The mixing should be done smoothly so that excess air is not introduced into the final mixture.

Curing reaction starts with the mixing, which leads to gradual increase in viscosity, followed by gelation and finally converting into a solid elastomer, which is transparent in nature. This mixture should be used within two hours after mixing. For preparing surface, pour the mixture on a flat surface and leave it for some time to form final elastomer substrate. Usually at room temperature, it takes 48 hours to give final silicone elastomer surface and at higher temperatures, the time taken to give the final elastomer is reduced as follows.

- ~48 hours at room temperature
- 45 minutes at 100°C (212°F)
- 20 minutes at 125°C (257°F)
- 10 minutes at 150°C (302°F)

For preparing a flat surface, the mixture should be poured on a flat surface and allowed to move freely without any obstructions. After two days simply peeling it off gives a plain transparent sheet of silicone elastomer as shown in Figure 2. By preparing surfaces with different proportions of very little amount of Aluminium powder along with base and curing agent, quantitatively find out the condensation rate on each surface of different Aluminium proportions

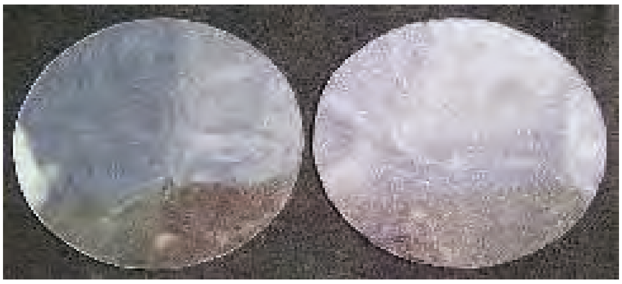

Figure 2. Plain PDMS substrate and PDMS with Aluminium particle inclusions.

B. Condensate measurements:

Experimental Procedure.: All the measurements are taken using micro weighing machine, TB-215D Denver instrument. It is convenient for analytical balancing with large display and clear function keys. It gives reliable weighing results under normal ambient conditions. For getting good accurate results follow the manufacturer instructions.

To deliver exact results, the balance must warm up for at least 30 minutes after initial connection to AC power or a relatively long power outage to reach the required operating temperature. After the balance has been turned on, an automatic self-test of the balance's electronic circuitry is performed. At the end of the self-test, zero readout is displayed. Then the balance is ready to operate. Before taking any measurements, press TARE option to make the defined zero point or initial value. Tarring can be done within the entire weighing range of the balance.

By maintaining one surface of the substrate at lower temperature, by keeping it on an ice block and leaving the other surface to atmospheric conditions, the humidity present in the atmosphere condense on the surface that is open to atmosphere and finally gives water droplets. For this to happen, there must be a temperature difference and the substrates are kept on ice block and left for some time. The procedure for measuring the condensate on each surface is as follows.

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First, dry weight of each material is measured with the use of a micro weighing machine. Then the materials are placed on an ice block and left there for some time about five minutes. Then measure the wet weight. Subtracting the wet weights and dry weights of the substrates gives condensate weights. This is repeated and all the values are tabulated. This procedure is followed for all other elastomer surfaces made up of different mass fractions of Aluminum inclusions. All the weight measurements are done with help of micro weighing machine. And all the measurements are taken in similar ambient conditions.

C. Relative Humidity:

Dew condensation rates on different substrates with different amounts of Aluminum metal powder inclusions are tabulated and humidity calculations are done by using wet bulb and dry bulb temperatures. By taking these dry and wet bulb temperatures and with the help of psychometric chart the percentage of relative humidity present in the room is determined. While taking the condensation measurements for the different concentrations of Aluminium powder included elastomer substrates, these dry bulb and wet bulb temperatures are taken in the surroundings.

III. Results and Discussions

A. Dew on plain metal surface and PDMS Surface:

By taking two metal pieces of same dimensions (here Aluminium metal plates) and comparing the dew formation on both plates, one is plain metal surface and other is a PDMS surface, it is observed that dew formation on PDMS surface is higher than on the plain metal surface. By pouring the elastomer mixture on surface of flat metal plate and allowing it to cool for about 48 hours at normal room temperature, the mixture gets solidified and gives a PDMS surface on metal plate. For comparing dew on these surfaces, both plates are maintained at lower temperature so that dew is formed on surface of the plates. For this, both plates are placed in a refrigerator for some time and after taking them out they are kept in atmosphere until dew is formed on the surface. When observed dew formation on metal with PDMS surface is higher than plain metal surface as shown in Figure 3.

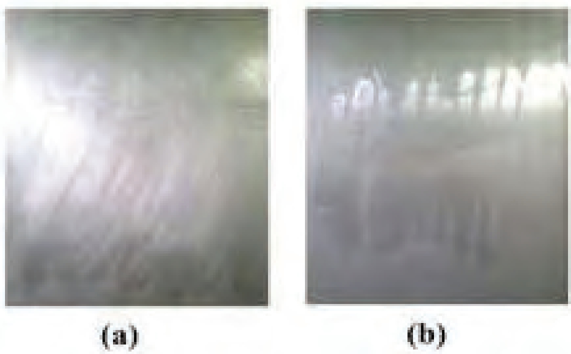

Figure 3 Dew formation on substrates (a) Plain metal surface (b) Plain PDMS surface

B. Dew measurement on different PDMS Substrates:

As dew formation on any substrate is controlled by surface properties and the wetting properties of the surface, PDMS surfaces are used with different amounts of Aluminium metal powder inclusions. These substrates are compared with each other quantitatively for dew formation. After preparing PDMS substrates with different amounts of Aluminium metal inclusions, condensate weights are measured with the help of micro weighing machine.

Dew water on substrates with different Aluminium metal inclusions is measured. All the measurements are taken by same micro weighing machine and each substrate is prepared with 20 grams of Silicone base material. The surface areas of all substrates are equal, and diameter of each material is 120 mm. The nucleation of metal in PDMS substrates cools faster and results in a good condensation on the substrate. Condensation of dew and formation of water droplets can be seen in following Figure 4.

Figure 4. Dew formation on PDMS substrates.

1. **Dew water condensation on substrates with 0.001, 0.002, 0.004 and 0.01 grams of Aluminium metal inclusions. Test time: 5 minutes**

I. Substrate 1: 20 g.Silicone + 0.001 g. Al powder.

TABLE I.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	10.1826	10.4100	0.2274
2	10.1822	10.4030	0.2208
3	10.1818	10.3907	0.2089
4	10.1820	10.4050	0.2230
5	10.1819	10.4325	0.2506

II. Substrate 2: 20 g. Silicone + 0.002 g. Al powder.

TABLE II.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	10.4046	10.6374	0.2328
2	10.4038	10.6369	0.2331
3	10.4038	10.6301	0.2263
4	10.4032	10.6345	0.2313
5	10.4033	10.6607	0.2574

III. Substrate 3: 20 g. Silicone + 0.004 g. Al powder.

TABLE III.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	11.2543	11.4946	0.2403
2	11.2537	11.4693	0.2156
3	11.2539	11.4613	0.2074
4	11.2538	11.4772	0.2234
5	11.2540	11.4950	0.2410

IV. Substrate 4: 20 g. Silicone + 0.01 g. Al powder. (Test time: 5 minutes)

TABLE IV.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	11.3696	11.6250	0.2554
2	11.3696	11.6148	0.2449
3	11.3698	11.5847	0.2149
4	11.3700	11.5899	0.2199
5	11.3693	11.6125	0.2432

From Table I to Table IV, data gives weights of condensed water for the substrates with 0.001, 0.002, 0.004 and 0.01grams of Aluminium metal included silicone elastomer substrates. Here only very few amounts of metal inclusions are added to maintain the transparency of the substrates to use them for the solar still applications. And from the values it is understood that with increase in metal inclusions, the condensate weight is also increased as expected.

2. Dew water condensation on substrates with 0.000, 0.008, 0.005, 0.01, 0.015, 2.00 and 5.00 grams of Aluminium inclusions is as follows.

I. Substrate 1: 20 g. Silicone + 0.000 g. Al powder. (Test time: 5 minutes)

TABLE V.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	12.137	12.2697	0.1327
2	12.1344	12.2442	0.1098
3	12.1348	12.2475	0.1127
4	12.136	12.2518	0.1158
5	12.1356	12.2566	0.121

II. Substrate 2: 20 g. Silicone + 0.005 g. Al powder. (Test time: 5 minutes)

TABLE VI.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	11.9855	12.0937	0.1082
2	11.9813	12.0804	0.0991
3	11.981	12.0873	0.1063
4	11.9831	12.0849	0.1018
5	11.9827	12.0854	0.1027

III. Substrate 3: 20 g. Silicone + 0.008 g. Al powder. (Test time: 5 minutes)

TABLE VII.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	11.7074	11.8198	0.1124
2	11.7037	11.8432	0.1395
3	11.7033	11.8189	0.1156
4	11.7037	11.823	0.1193
5	11.7051	11.824	0.1189

IV. Substrate 4: 20 g. Silicone + 0.01 g. Al powder. (Test time: 5 minutes)

TABLE VIII.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	12.5335	12.6451	0.1116
2	12.5296	12.6622	0.1326
3	12.5299	12.676	0.1461
4	12.529	12.6773	0.1483
5	12.5288	12.6691	0.1403

V. Substrate 5: 20 g. Silicone + 0.015 g. Al powder. (Test time: 5 minutes)

TABLE IX.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	11.1329	11.2232	0.0903
2	11.1293	11.2545	0.1252
3	11.1286	11.2421	0.1135
4	11.1295	11.2393	0.1098
5	11.1288	11.2464	0.1176

VI. Substrate 6: 20 g. Silicone + 2.0 g. Al powder. (Test time: 5 minutes)

TABLE X.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	12.3042	12.4087	0.1045
2	12.3014	12.4168	0.1154
3	12.3004	12.3942	0.0938
4	12.301	12.3962	0.0952
5	12.3016	12.409	0.1074

VII. Substrate 7: 20 g. Silicone + 5.0 g. Al powder. (Test time: 5 minutes)

TABLE XI.

Test No.	Dry weight, g	Weight after condensation, g	Condensate Water weight, g
1	12.358	12.4617	0.1037
2	12.3568	12.4571	0.1003
3	12.3561	12.441	0.0849
4	12.357	12.4732	0.1162
5	12.3565	12.451	0.945

From the above set of tables, the values of dry weights, wet weights and condensate weights are calculated and compared for the different values of Al particle inclusions.

C. Relative humidity measurement:

The relative humidity varies from 52% to 46% within the span of two hours. Where dry bulb temperatures are 32 ^{0}C to 33 ^{0}C and wet bulb temperature is 24 ^{0}C. From the measurements of relative humidity, by calculating mass fraction of Al for each substrate.

TABLE XII.

S. No.	Mass fraction of Aluminium	Mean condensation rate, g/s	Standard deviation, g/s
1	0	344.92	0.87
2	0.0002499	364.17	4.67
3	0.0003998	374.67	12.33
4	0.0004998	407.0	4.33
5	0.000749	369.08	2.67
6	0.0909091	344.0	2.33
7	0.2	341.08	1.77

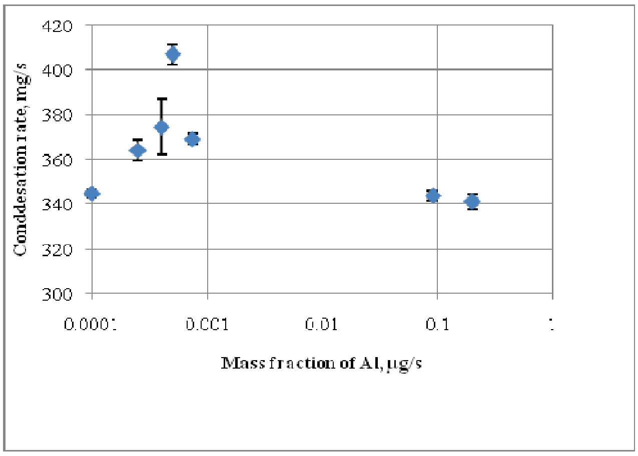

Figure 5. Condensation rate to the mass fraction of Aluminium

From the above graph, the rate of condensation on silicone substrate is gradually increasing and then decreasing with the addition of Aluminium powder to the silicone elastomer. For the weight of 0.010 g. Aluminium powder the substrate is giving more condensed water. From 0 g. to 0.010 g., condensation rate is gradually increasing. And with more amounts of Aluminium powder inclusion, condensation rate is decreasing.

IV. Conclusions

Summary

The objective is to understand the working of a solar still and to improve its efficiency by using alternative PDMS surfaces. By replacing conventional transparent glass surfaces with these PDMS substrates with small amounts of metal inclusions, better condensation rates are possible. And without changing any wetting properties of the surfaces there is a possibility of getting good amount of distilled water without using any electrical or mechanical power. A sheet of polyethylene, assuming that there is no evaporation and that all the condensed water flows into a vessel, should yield approximately 1liter per square meter surface area under the meteorological conditions. Hence, practical utilization of dew contained in the air is possible. Further by including small amounts of metal inclusions in these PDMS substrates, the condensation rate is varying and for a particular amount of inclusions, condensation is the maximum depending on the ambient conditions.

Future Work

It is found that the condensation efficiency of water is higher with partial introduction of Aluminium nucleation sites. And aslo it is observed that the condensation efficiency is a non-monotonic function of the Aluminium mass fraction in the substrate, where peak condensation efficiencies were observed at a critical mass fraction of Aluminium.

Future work can take advantage of these conclusions by building a solar still that uses PDMS / Al substrates as condensation surface and manifest higher condensation efficiencies than either pure PDMS or pure Aluminium surfaces. In addition, the partial introduction of Al into PDMS maintains the transparency characteristics of the surface, allowing sunlight to pass through the substrate.

References

[1] Prof. Alpesh Mehta “Design of solar distillation system”. *International journal of advanced science and technology*, vol 29, April 2011.

[2] D. Beysens, "The formation of dew" *Atmospheric Research* 39 (1995) 215-237.

[3] Jaffrin, A., Makhlouf S., Scotto la Massese C., Bettachini,A. ansVoisin, R., 1989.Sigsbee, R.A., 1969. “Vapor to condensed-phase heterogeneous nucleation. In: A.C” Zettlemoyer (Editor), Nucleation. Marcel Decker, New York, pp. 151-224.

[4] Platten, J.K.and Legros, J.C. “Convection in liquids”. Springer, Heidelberg.

[5] Family, F.and Meakin, P., “Scaling of the droplet-size distribution in vapor-deposited thin films.” *Phys. Rev. Lett.,* 61: 428-431.

[6] V.S. Nikolayev, D. Beysens, A. Gioda, I. Milimouk, E. Katiushin, J.P. Morel. “Water recovery from dew”. TB-215D, *Pinnacle series Analytical and precision balances*.