Analysis of adhesion of dust particles on glass surfaces

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ABSTRACT

We examined the composition of the accumulated dust on a plane glass surface (12x12 cm^2) in Baghdad city for both a flat horizontal surface, and a tilted surface at (50^o, 70^o, 80$^{o)}$ with horizon, the missing elements were found out . The step wise variation of the amount of dust sliding off have been measured. The retention at different angles was attributed to inter dust-layer friction resulting from different particle size distributions.

Keywords: dust, adhesion, friction , clear factor , sedimentation.

1. INTRODUCTION

The accumulation of dust on the surface of a photovoltaic module decreases the radiation reaching to the solar cell and produces losses in the generated power. Dust not only reduces the radiation on the solar cell, but also changes the dependence on the angle of incidence of such radiation. The measurements of the size distribution of dust particles and the different effects resulting there have been extensively dealt with by Irani and Callis (1963)[1]. Also by Allen (1981)[2]. Cross and Farrer (1982) [3] have reviewed dust explosion causes and correlated such events to particle size. the subject of adhesion of dust and powder has been well covered by Zimon (1982) [4]. Lorrain (2007) had studied the effects of various fundamental forces on the adhesion of fine dust particles . he compared the particle-size and distance variation of surface-energy related (e.g., van der Waals) forces to similar relations for static-electric forces for tribo-charged particles near (or contacting) surfaces. He found that the van der Waals force (between macroscopic spheres), a patch charge image-force and static-electric image-forces all exhibit an inverse square variation with distance[5]. M. Man had studied the impact of dust on solar photovoltaic performance (2010) [6]. Adhesion of Dust Particles to Common Indoor Surfaces in an Air-Conditioned Environment was studied by Cher Lin Clara Tan and Shaokai Gao in (2014)[7]

2. EXPERIMENTAL

This work was managed in two steps:
First, we examined the composition of the dust powder obtained from 30 days accumulated dust on a flat glass surface by fluorescence x-ray device , then we repeated the test on the retained dust for three tilting angles α(50^o, 70^o, 80^o). Second, two identical glass sheets (12x12) cm^2 ,were placed flat on the roof top of a 120 m building height, and exposed to the atmosphere for a period of 30 days, where the dust collected under gravity forces. One of the sheets was immediately subjected to analysis as outlined below, the other after 3 days. The procedure was based on tilting the sheet at an angle (α) and weighing the dust sliding off. Particle size analysis were carried out using a laser optical photometer, worked under computer control, for automatic counting of particles and fibers.

3. RESULTS AND DISCUSSION

X-Ray fluorescence test for dust samples
In order to examine the composition of the dust, we made a basic reference test for the accumulated dust samples taken from the surface of the glass sheet, the result showed presence of so many elements as it is shown in table (1). These different elements differ in their molecular weight, conductivity and diameter. Unfortunately some of them are very harmful for the environment and human health. Furthermore we made experiments for dust components which were resident on the glass surface considering different tilting angles α. . Results are organized and discussed in the following sections and tables.

Table (1) : The composition and availability of the dust on a plane surface.

Element	Availability (ppm)	Molecular Weight (g/mol)	Electrical conductivity (S/m)
Calcium (Ca)	111669.07775	40.078	2.98 * 10^7

Tin (Sn)	1555.09577	118.71	0.917 * 10^7
Titanium (Ti)	2012.57804	47.867	0.238 * 10^7
Iron (Fe)	28490.90414	55.845	1 * 10^7
Zinc (Zn)	511.78923	65.409	1.69 * 10^7
Manganese(Mn)	362.47426	54.938049	0.69 * 10^7
1) *Strontium (Sr)*	394.37986	87.62	0.758 * 10^7
Zirconium (Zr)	210.09176	91.224	0.238 * 10^7
Copper (Cu)	180.33809	58.6934	1.43 * 10^7
Nickel (Ni)	166.71896	250.03961	5.96 * 10^7
Lead (Pb)	137.35998	207.2	0. 455 * 10^7
Gallium (Ga)	65.18051	69.723	0.37 * 10^7
2) *Atrium (Y)*	41.61326	88.90585	0.168 * 10^7
Rubidium(Rb)	33.43892	85.4678	0.781 * 10^7
Chrome (Cr)	19.68949	51.9961	0.8 * 10^7
Antimony (Sb)	3.06229	121.761	0.24 * 10^7
Arsenic (Ar)	1.72596	74.9216	0.3 * 10^7
Silver (Ag)	0.13623	107.8682	6.3 * 10^7

Table (2) shows the results for The missing elements from the dust sample for angle (α =50^o). zarticularly in the following table we notice that tilting the glass sheet results in rolling down of lead ,rubidium, Chromium, Copper, and Nickel. Generally we noticed that particles were repelled and rolled off the surface once we tilted the surface. Also we noticed the absence of some more elements like Zr, Cu, Ag, Sn, Sb, As, Ni, and Pb particles. this may be attributed to the impact of the outcome of several factors like their small presence percentage , their relatively light weight, their geometric shape and their high electrical conductivity, like Ag and Cu. Now as a general look to the tables we concluded that the elements that roll down the surface are not so critical to the particle diameter .

Table(2): The missing elements from the tilted samples .

α= 50o	α= 70o	α= 80o
Sn	Sn	Sn
Cu	Cu	
Ni	Ni	
Sb	Cr	Cr
As	As	As
Ag	Ag	Ag

Dust particles collected on the surface occurred under the effect of the gravity pull and sometimes also under the electro static attraction, these particles gets held when it becomes in contact with surface by adhesion pull, and successively dust layers accumulate on the top adhesion layer (figure 1).

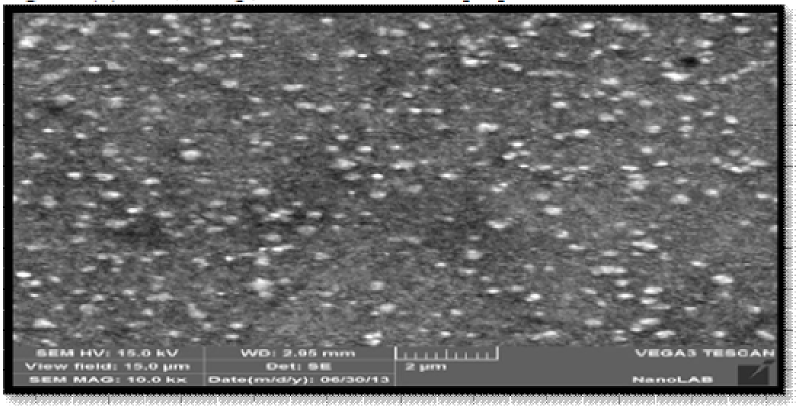

Figure (1): scanning electron microscope view of the dusty glass sheet.

When the surface is tilted through an angle (α) , dust layers begin to slide off, one over the other, when the weight component parallel to the surface (mg sin α) for each layer exceed the inter-layer friction. It is assumed here that the particles of each layer deposited during different intervals of time, will have a different size distribution profile. This latter assumption has been verified by size distribution analysis of the dust samples collected after each angle of inclination, α , change, table (3).

Table (3): angle- size distribution values for plate A and B.

Particle size (µm)	50^o A%	50^o B%	70^o A%	70^o B%	80^o A%	80^o B%	90^o A%	90^o B%	Retained A%	Retained B%
0.4- 0.5	42.14	-	32.91	38.07	-	36.42	-	39.20	38.65	35.47
0.5- 0.6	35.17	-	32.56	32.78	-	35.59	-	32.59	32.44	34.38
0.6- 0.7	15.04	-	18.78	15.98	-	15.88	-	16.39	15.61	16.22
0.7- 0.8	4.44	-	9.04	7.61	-	6.40	-	6.84	7.48	8.19
0.8- 0.9	1.63	-	3.93	2.52	-	2.25	-	2.88	3.10	2.92
0.9- 1.0	0.61	-	0.93	1.38	-	1.29	-	0.84	1.13	0.97
1.0- 1.1	0.24	-	0.80	0.71	-	0.46	-	0.48	0.66	0.68
1.1- 1.2	0.29	-	0.26	0.32	-	0.21	-	0.12	0.42	0.40
1.2- 2.0	0.45	-	0.26	0.63	-	0.46	-	0.66	0.52	0.57
2.0	0.00	-	0.02	0.00	-	0.04	-	0.000	0.00	0.00

Table 4: Variation of weight of sliding dust with the angle of inclination.

tilt angle	12^o A B	20^o A B	50^o A B	70^o A B	80^o A B	90^o A B	120^o A B	140^o A B	160^o A B	180^o A B	Retained A B
w	- 0.0	- 0.1	33.7 20.15	101.13 131.21	27.24 23.07	25.82 8.37	4.0 3.3	45.16 45.91	0.04 -	0.17 0.83	69.52 69.9

At first glance , it is clear that the size profiles of dust collected at different angle of inclination (α= 50 ^{o}- 70 ^{o}) and for dust retained (α = 180 ^{o})are vastly different. From table 4 , one can find the friction force (mg sin α) and parting force (mg cos α). If we compare these profiles against the angle of inclination , we could deduce that the layers of different profiles are prevented from slide by different friction forces. In other words, the friction forces has been shown to depend on the size distribution profiles of both the sliding and the stationary layers . the magnitude of the friction force may also be an indicator of the degree of the particle- surface match of the two layers. Hence the fact that no appreciable dust slide was observed at bellow 50^o . this may be attributed to the last deposited layers which being too loosely held to the retained on the earlier deposited layer.

The variation of the friction force with α is as follows:

For α ≤ π / 2, the magnitude of the force parallel to the surface which brings about dust slide is equivalent to (mg sin α)
For α > π / 2 the effective force causing the parting of the dust particle from the surface or from other layers should exceed (mg cos α). Other – wise (mg sin α) should exceed the friction force. For (α = 180 ^{o}) only the adhesion layer is retained. Comparing total weight – sliding off to the total weight (including the weight of the retained dust at (α = 180 ^{o}) , we find that 77.34% from the weight of the dust which accumulate in the glass surface can be removed by simply turning the glass sheet upside down.

4. CONCLUSION

Finally it is necessary to do this measurements in the solar collector and cells in actual use, and to study all the parameters including the collector material, site, type of dust(weight profile, size distribution profile) and the reduction in light intensity caused by this type of dust. The last two parameters can be assessed by experiments.

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REFERENCES

[1] Irani ,R. &CALLIS ,C:particle size measurement interpretation and application .John Wiley and Sons Inc.1963
[2] Allen , T:particle size measurement. third edition.Chapman and Hall 1981.
[3] Cross ,J .& Farrer ,D:Dust explosions .plenum press ,new York.1982.
[4] Zimon, A,D, adhesion of dust particles, springer, Second edition ,consultants Bureau ,New York.1982.
[5] Lorrain ,NASA/CR—2007-214685, Otis R. Walton,Grainflow Dynamics, Inc., Livermore, California, National Aeronautics and Space Administration Glenn Research Center,Cleveland, Ohio 44135, april 2007.
[6] M. Mani, R. Pillai. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations, Renewable and Sustainable Energy Reviews 14, pp. 3124-3131(2010).
[7] Cher Lin Clara Tan and Shaokai Gao, Adhesion of Dust Particles to Common Indoor Surfaces in an Air-Conditioned Environment, Aerosol Science and Technology,Vol. 48, Issue 5, 2014.