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Steam Generation by Localizing Heat Due to Solar Thermal Energy using GO and rGO

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Abstract:

GO suspended in water when exposed to Solar Radiation using Fresnel lens, absorbs energy and make the water around it vaporized. Steam generation from the nanoparticle solution occurs in small, micro explosive "bursts". Since the water vaporizes due to localized heating, the temperature of the water at the bottom of the tube don't show any rise in the temperature. So the energy loss in heating the bulk of water is avoided.

Keywords: GO, rGO

Introduction:

In the developing countries like India availability of Energy Sources are not uniformly distributed throughout the land, hence many places are underprivileged of Electricity and Fossil Fuels. Processes like turbine rotation, sterilizations are the keywords for the generation of electricity and health related activities. Steam plays an important role in the progress but it is constrained. In such Energy crises, Solar Energy stands as a promising solution for the same. At the same time Nano materials are miraculously substituting many complicated processes. Many are developing methods to trap Solar Energy effectively and more efficiently with the help of Nanoparticles' broad absorption spectra.

Naomi Halas and her research group at Rice University (TX, USA) [1,4] found that if nanoparticles made up of silica and encapsulated with gold are immersed in water, steam is generated without heating the entire water volume to the boiling point. When the solution is irradiated by sunlight. In this process of steam formation, each nanoparticles, absorbs UV and heats up. It transfers energy to the surrounding water.

Gang Chen et al[2] generated steam by developing a double-layer structure (DLS) consisting of a carbon foam layer supporting an exfoliated graphite layer.

As per Albert Polman[3], nanoparticles are strong absorbers of light. The thin shell of water around the nanoparticle which comes in direct contact with the nanoparticles rapidly gets heated above its boiling point to transform into steam. But steam is a poor conductor of thermal energy, hence transfer of heat from the heated particle to the water is prevented. Because the nanoparticle gets further heated by the sunlight; the thickness of the steam shell keeps growing gradually. Once the steam shell reaches a thickness of several hundred nanometers, the weight of the steam/nanoparticles assembly becomes less than that of an equivalent volume of water and, as a consequence, it buoys toward the surface. Finally, the steam bubble annihilates at the surface and steam escapes from the water. In this way, steam is generated without heating the entire water volume to the boiling point.

Here we show that Graphene Oxide can be used for the generation of the steam. Graphene Oxide is exfoliated Graphite Oxide (GO). The typical UV-Visible absorption spectrum of aqueous solution of GO shows a Plasmon peak near 230 nm[4] due to the π–π^* transition and a hump around 300 nm often attributed to n–π^* transitions of C = O.[5]

Sunlight in space at the top of Earth's atmosphere (see solar constant) is composed of about 50% infrared light, 40% visible light, and 10% ultraviolet light, for a total ultraviolet power of about 1400 W/m^2 in vacuum. At ground level sunlight is 44% visible light, 3% ultraviolet (with the Sun at its zenith), and the remainder infrared. Thus, the atmosphere blocks about 77% of the Sun's UV, almost entirely in the shorter UV wavelengths, when the Sun is highest in the sky (zenith). Of the ultraviolet radiation that reaches the Earth's surface, more than 95% is the longer wavelengths of UVA, (Ultraviolet A: 320–400 nm wavelength with 3.10–3.94 eV

Photon Energy) with the small remainder UVB (Ultraviolet A: 290–320 nm wavelength with 3.94–4.43 eV Photon Energy).

The absorption spectrum of Graphene Oxide shifts towards longer wavelength with increase in size as well as it shifts towards longer wavelength when it reduces. Probably this gives the broad absorption spectrum to the Colloidal Graphene Oxide.

Experimental Details:

Graphene Oxide is synthesized in laboratory in by Hummer's Method. 2 g of Graphite Flakes are added to a solution of 98.3 ml of H2SO4 and 10.6 ml of H3PO4. After stirring the solution for 5 minutes 10 g of KMnO2 is added slowly to overheating. This solution is stirred for 3 days till slurry is formed. 40 ml H_2O_2 is added in 500 ml Deionized H_2O. The slurry is added to H_2O_2 mixture to stop oxidation. Decanted and washed with 1M HCl to remove all the salts formed during the reaction. Finally, it is washed with DI H_2O till it reaches pH 7. Then the residue is dried at room temperature. The XRD shown in **Fig. 1** supports[6] the formation of Graphene Oxide around $2\theta = 10^0$ with (001) plane.

The SEM of the colloidal solution also confirmed the formation of thin nano sized sheets of GO. It can be seen in SEM images in **Fig. 2.**

Colloidal solutions of Graphene oxide were prepared with different weight to volume ratios of Graphene Oxide in DI water. The samples have weight to volume ratios in mg/ml for Graphene Oxide in DI Water was from 3.33 % to 50 %.

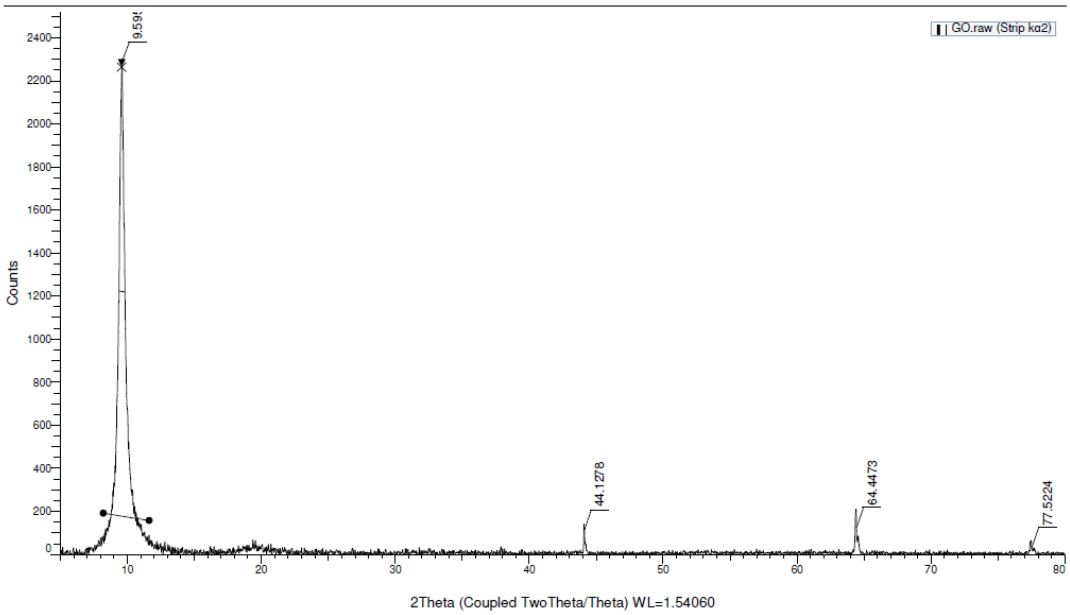


Fig. 1: XRD

Quartz does not absorb UV light. So the material chosen for colloidal solution is quartz. A vacuum jacketed quartz glass tube of 15 ml capacity was fabricated.

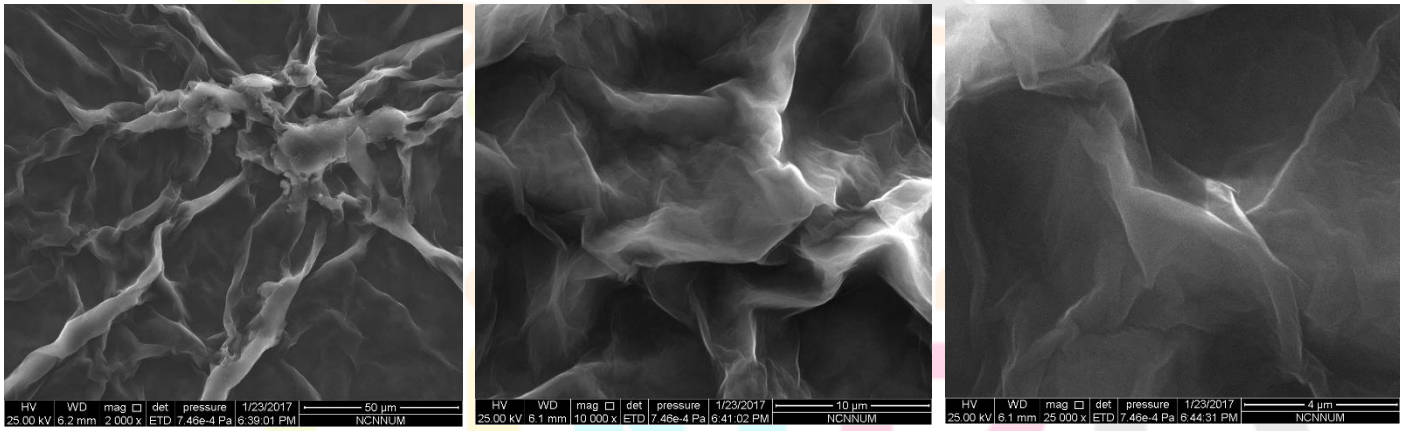


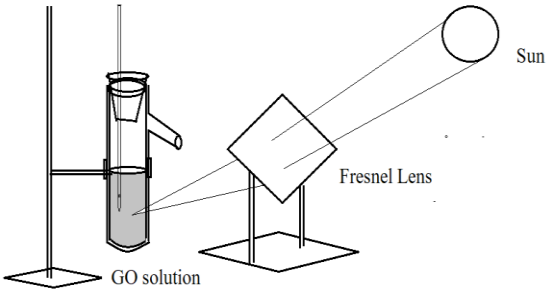
Fig 2 SEM images of GO

The colloidal solution sample was placed in the tube. The tube was closed by a silicon cork. K type thermocouples were inserted in it such that one measured the temperature of water at the bottom of the tube and the other measured the temperature of the steam. The top portion of the solution was focused with a Fresnel lens (Size: 26.3 cm X 20 cm, Focal Length: 28.5 cm). The schematic diagram and actual photograph of the experimental set up is shown in fig. 3 and 4.

Results and Discussions:

Colloidal solution of Graphene Oxide is placed in vacuum jacketed quartz tube. Solar radiations are focused on the surface of the solution for 10 minutes. The temperature at the outlet for the steam and that of the liquid at the bottom of the tube was noted. It started rigorously boiling near the focus point within one minute. Small explosions were observed at the surface of the water. The temperature of the vapors at the mouth of the tube which did not have vacuum jacket reached to 103^0C to 104^0C within 1 minute (Fig. 5). The temperature could not rise because that due to loss of heat due to air convection. The temperature of the liquid at the bottom of the tube still remained at around 48^0C to 52^0C depending upon the intensity of the sun (Fig. 6). It did not start boiling thus no bulk boiling was observed. The change in the volume and hence the mass of the generated steam were recorded (fig. 7). The experiment was repeated for samples of colloidal solutions with mass to volume ratios 6.66%, 16.66%, 26.66%, 33.33%, 40% and 50%. Appreciable mass loss in water was observed in 10 minutes (fig. 8).

GO converts to rGO during the solar exposure. But still it continues to absorb radiation and give localized heat production.



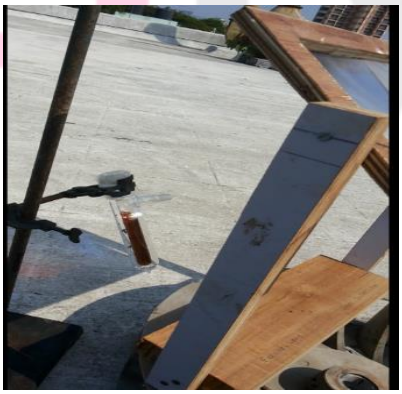
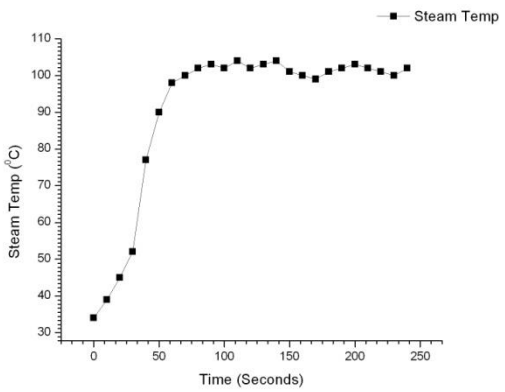


Fig. 3: Schematic diagram of the experimental set up **Fig. 4: Photograph of the experimental set up**



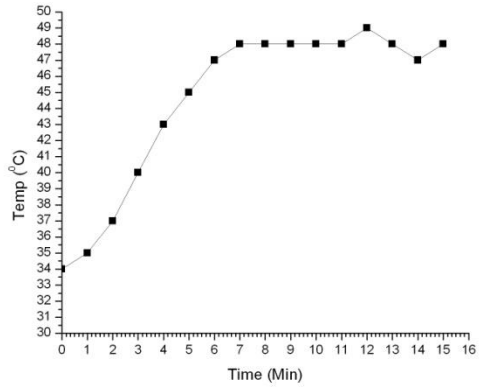
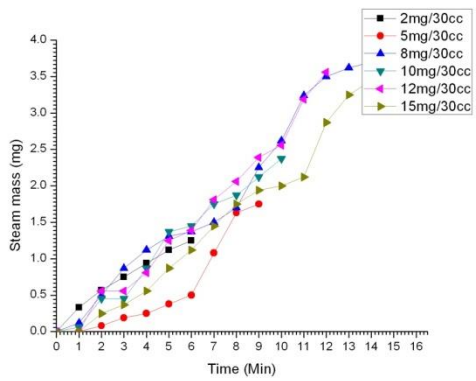


Fig.5: Temperature Vs Time graph for the Generated steam

Fig.6: Temperature Vs Time graph for the solution at the bottom



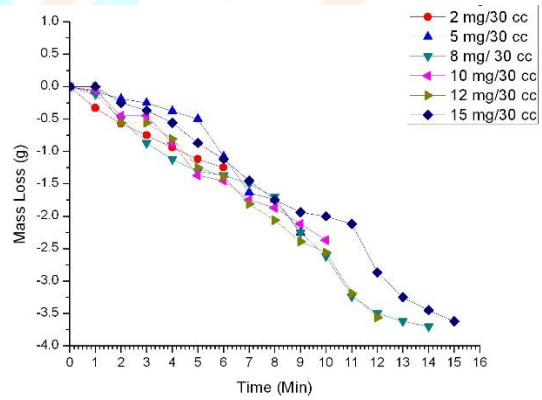


Fig.7: Mass of steam generated Vs Time graph for Colloidal Solution of Graphene in water with various mass per volume ratios.

Fig. 8: Mass loss of water due to steam generation Vs Time graph for Colloidal Solution of Graphene in water with various mass per volume ratios.

The Graphene oxide particles were observed to remain at the bottom and they were not passed with the steam. When only DI water was irradiated with the Fresnel lens, it could reach up to 72^0 C in 20 minutes and the temperature could not rise above it because of dominating air convection.

Conclusion:

Conductivity of Graphene Oxide increases with the progress in reduction.[6] Graphene Oxide when irradiated with solar energy, shows maximum absorption at the resonance with the Localized Surface Plasmon frequency. When they are absorbing energy, they don't give back the light energy through light scattering, but it results in the increase in the temperature of the particle structure. This is called as localized heating. This localized heating can be used to generate steam. Excited nanoparticles transfer their heat to the surrounding water molecules their by forming nano-bubbles of the steam which consequently coalesce with the neighboring nano-bubbles to form bubbles which come up to the surface with buoyancy and the steam escapes.

In the country like India, where energy crises are there, steam produced by this method can be used for sterilization of surgical instruments as well sterilization of waste as well in the waste management process.

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