



RESEARCH ARTICLE

GUANIDINE DELIVERY BY Si-DOPED C<sub>60</sub> AND SWCNT: A DFT APPROACH

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Abstract

The interactions between guanidine and silicon decorated fullerene or single walled carbon nanotube were examined for insight into the drug delivery approach. The calculations show that the chemical reactivity and interaction energies are strongly dependent on the interaction site of the guanidine molecule. Depending on the purpose, by determining the interaction sites, it is possible to use Si decorated fullerenes and single walled carbon nanotubes as selective drug delivery vehicles. The results will contribute to further searches on improving drug delivery platforms.

Keywords

Guanidine,  
Fullerene,  
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1. INTRODUCTION

Guanidines are known as nitrogen rich small organic compounds having found large scale application areas. Guanidines and their derivatives are part of different biological molecules including arginine and agmatine [1, 2]. Moreover, guanidine containing drug molecules are center to many clinical assessments due to their versatile pharmaceutical properties [3, 4]. It is also known that guanidine groups show very good hydrophilicity and anti-algal growth characteristics and further, the amino site in the guanidine molecule plays an important role as an active uranium adsorption site [5, 6].

Nanotechnological materials have been lately grasping considerable attention among the scientific community. Especially carbon-based materials such as fullerenes carbon nanotubes (CNTs) have found many scientific application possibilities including drug delivery and sensor applications due to their inherent physical and chemical properties [7-10]. The main drawback for possible medicinal applications of fullerenes and CNT based systems appears as their solubility problems. However, this problem might be overcome by adding impurity atoms while keeping the system structurally stable [11].

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In the scope of this work, based on density functional theory (DFT) calculations, possible interaction sites, electronic and some important vibrational properties of silicon decorated fullerene (SiC<sub>59</sub>) and single walled carbon nanotube (Si@SWCNT) towards the guanidine molecule have been investigated. The reactivity and sensing assessments of SiC<sub>59</sub> and Si@SWCNT against the guanidine molecules have been also examined. All the obtained results were discussed in brief.

## 2. CALCULATIONS

For the optimization process of the examined structures, the following procedure was followed: first, guanidine molecule, C<sub>60</sub> and SWCNT structures were optimized. Then one carbon atom on the surface of C<sub>60</sub> and SWCNT was replaced with one silicon atom and the resultant structures were re-optimized. Based on the charge distribution on the surface of the guanidine molecule (See supplementary file) interaction sites were determined. Finally, the optimization process of the interacted systems was carried out. To reach a real global energy minimum, at the end of each optimization process, vibrational frequency calculations were also performed to see if no negative frequencies were observed at the end of each calculation. In any case where there appear any negative frequencies, the optimization process was repeated to reach a result that is free of all possible negative vibrational frequencies. The computations were carried out in both the gas phase and in the water media to see the solvation effect. The effect of solvent media was taken into account using the polarizable continuum model [12].

The binding energy (E<sub>b</sub>) between guanidine and SiC<sub>59</sub> or Si@SWCNT was calculated using the following equation:

$$E_b = E_{\text{Guanidine}\&\text{SiC}_{59}} - (E_{\text{Guanidine}} + E_{\text{SiC}_{59}})$$

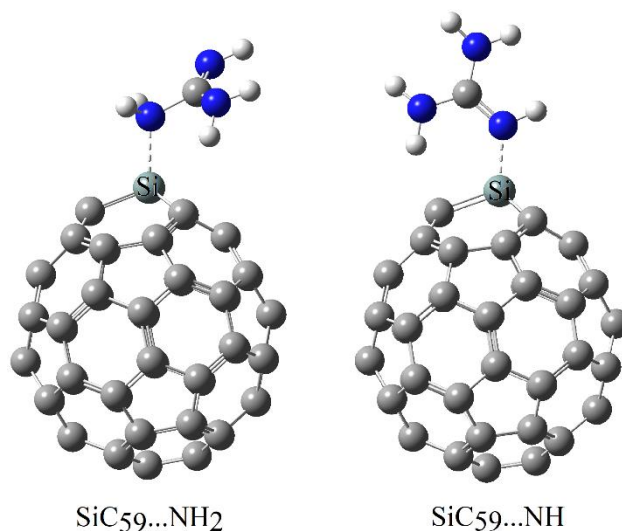
$$E_b = E_{\text{Guanidine}\&\text{Si@SWCNT}} - (E_{\text{Guanidine}} + E_{\text{Si@SWCNT}})$$

where all the structures given above are the optimized energies of the related structures. In the given equations, the structures with more negative E<sub>b</sub> values are referred to as the most stable structures. E<sub>g</sub> energies are taken as the magnitudes of differences between the highest occupied molecular orbitals (HOMO) and the lowest unoccupied molecular orbitals (LUMO). E<sub>b</sub> values were recalculated to get rid of possible basis sets superposition errors (BSSE) by including the counterpoise correction method [13]. For all calculations, the B3LYP/6-31G(d) level of theory was preferred due to their acceptable results [14, 15]. It can be used to investigate the binding energy and reactivity properties for such interactions of the compounds compared to the highly demanding cc-pvdz basis set [16]. Gaussian and GaussView programs were used for DFT computations, molecular design of the examined systems and visualization [17, 18].

## 3. RESULTS AND DISCUSSIONS

### 3.1. Analysis of SiC<sub>59</sub> Interacted Guanidine System

The optimized structures of the guanidine interacted SiC<sub>59</sub> system are given in Figure 1. Si...NH<sub>2</sub> and Si...NH inter-atomic distances were calculated as 1.983 & 1.841 Å in the gas phase and 1.940 & 1.799 Å in the water media, respectively. It was observed that Si...N inter-atomic distances are shorter in the water media leading to more stable structures. This fact can also be verified from the analysis of E<sub>b</sub> energies which were calculated as -39.87 & -50.70 kcal/mol for gas and water media calculations for Si...NH interacted system. As for the Si...NH<sub>2</sub> interacted system, E<sub>b</sub> energies were found as -15.78 & -21.76 kcal/mol correspondingly. It is seen that systems are more stable in water media and the strongest interaction occurs at the NH site of the guanidine molecule.



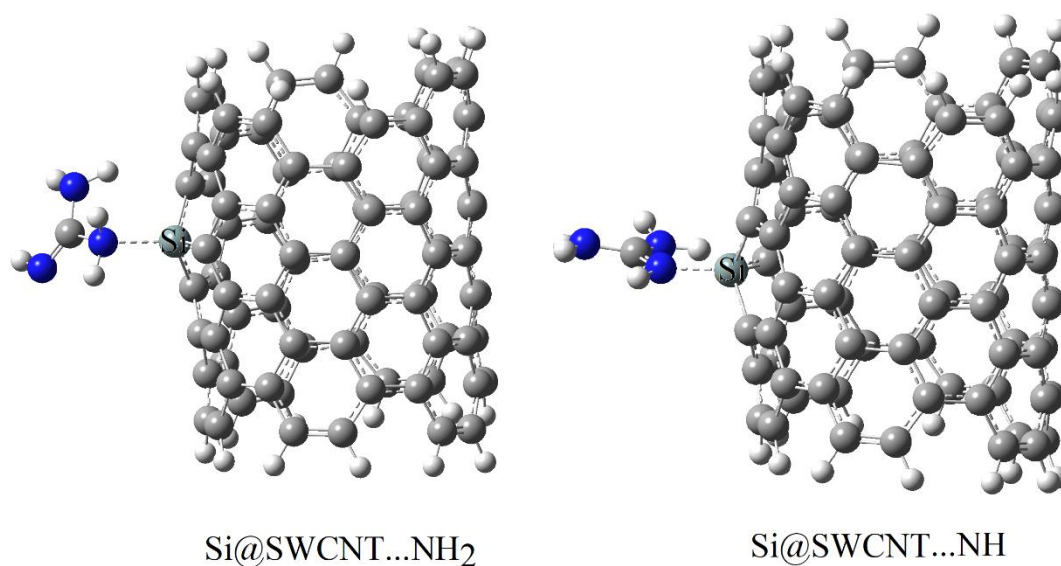
**Figure 1.** The optimized structures of the guanidine interacted SiC<sub>59</sub> system in the gas phase.

NH or NH<sub>2</sub> stretching vibrations can easily be identified in the IR spectrum. Therefore, at this point, it is better to analyze the alterations of NH or NH<sub>2</sub> stretching vibrations before and after the interaction of the examined systems. NH<sub>2</sub>-asymmetric stretching (as), NH<sub>2</sub>-symmetric stretching (ss) and NH-s vibrations (scaled by 0.9614 [19]) for the isolated guanidine were calculated (gas & water media) as 3499 & 3501, 3396 & 3405 and 3332 & 3332 cm<sup>-1</sup>, respectively. Following the NH<sub>2</sub> site interaction of the guanidine molecule with SiC<sub>59</sub>, NH<sub>2</sub>-as and NH<sub>2</sub>-ss vibrations (gas & water media) were shifted to 3350 & 3339 and 3274 & 3275 cm<sup>-1</sup>, respectively. The results suggest a red-shift in the IR spectra upon interaction. Further, as for the NH site interaction of the guanidine molecule with SiC<sub>59</sub>, NH-s vibrations (gas & water media) shifted to 3425 & 3424 cm<sup>-1</sup>. The blue shifts are more dominant when with NH site interacts fullerene system since as indicated the interactions are stronger with the NH site of the guanidine molecule when compared to the NH<sub>2</sub> site. Therefore, the obtained results support each other.

Single isolated SiC<sub>59</sub> produced E<sub>g</sub> values of 2.169 and 2.170 eV in the gas and water phases. Upon interaction from NH<sub>2</sub> and NH site of guanidine, these values (gas & water media) decreased to 2.092 & 1.998 eV and 2.143 & 1.968 eV, respectively. The decrease in E<sub>g</sub> values proposes that no matter which site or which phase the interaction occurs, SiC<sub>59</sub> is sensitive to the presence of guanidine molecule.

### 3.2. Analysis of Si@SWCNT Interacted Guanidine System

The optimized structures of guanidine interacted Si@SWCNT system are given in Figure 2. Si...NH<sub>2</sub> and Si...NH inter-atomic distances were computed as 2.036 & 1.869 Å in the gas phase and 1.981 & 1.819 Å in the water media, respectively. E<sub>b</sub> energies were found as -9.09 & -13.02 kcal/mol for gas and water media calculations for Si...NH<sub>2</sub> interacted system. As for Si...NH interacted system, E<sub>b</sub> values were calculated as -28.29 and -38.07 kcal/mol, respectively. As it happens for silicon decorated fullerene systems, here water as solvent stabilizes the examined silicon decorated SWCNT system and yields more negative E<sub>b</sub> energies with respect to gas phase calculations. The strongest interaction also occurs with the NH site of the guanidine molecule.



**Figure 2.** The optimized structures of the guanidine interacted Si@SWCNT system.

Following the NH<sub>2</sub> site interaction of guanidine molecule with Si@SWCNT, NH<sub>2</sub>-as, NH<sub>2</sub>-ss vibrations (gas & water media) were shifted to 3368 & 3357 and 3287 & 3270 cm<sup>-1</sup>, respectively. When compared to the isolated guanidine molecule, a red-shift was observed for the interacted system. Moreover, as for the NH site interaction of the guanidine molecule with Si@SWCNT, NH-s vibrations (gas & water media) shifted to 3415 & 3418 cm<sup>-1</sup>.

Single, isolated Si@SWCNT yielded E<sub>g</sub> values of 1.719 and 1.706 eV in the gas and water phases. After the interaction from NH<sub>2</sub> and NH site of guanidine, the related values (gas & water media) altered to 1.756 & 1.729 eV and 1.740 & 1.689 eV, respectively. The obtained results here are quite different from the results obtained with fullerene interacted systems. The only decrease in E<sub>g</sub> values for Si@SWCNT interacted guanidine system was observed for NH site interaction in the water phase. Therefore, it can be concluded that, if the interaction between Si@SWCNT and guanidine molecule occurs at the NH edge in water media then the Si@SWCNT system is sensitive to the presence of guanidine molecule otherwise it is not.

#### 4. CONCLUSIONS

In this study, the interactions between guanidine molecule and silicon decorated fullerene C<sub>60</sub> and single walled carbon nanotube were examined by DFT calculations. It was observed that the strongest interactions occurred at the NH site of the guanidine molecule and the strength of the interactions is far stronger with the fullerene system compared to the SWCNT system. It was also observed that water as a solvent and the site of interaction have impacts on the sensitivity of the fullerene and SWCNT systems towards the guanidine molecule. By defining the interaction site of the guanidine molecule, the electronic properties of the interacted systems can be manipulated in a preferred manner.

#### CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

## CRedit AUTHOR STATEMENT

**Shohrat Ovezov:** Investigation, Software, Writing - original draft. **Cemal Parlak:** Supervision, Writing – Review & Editing, Software, Visualization. **Özgür Alver:** Conceptualization, Formal analysis, Methodology.

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