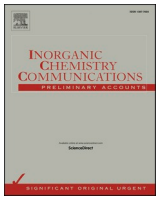
Inorganic Chemistry Communications 155 (2023) 111115

Contents lists available at ScienceDirect

Inorganic Chemistry Communications

journal homepage: www.elsevier.com/locate/inoche



Short communication

Investigation of adsorption of Fluorouracil as anticancer drug on C_{82}, Si_{82}, Ti-C_{82} and Ti-Si_{82} nanocages

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ARTICLE INFO

Keywords:
Anticancer
Drug delivery
Adsorption
Fluorouracil
Nanocages
Solvent effect

ABSTRACT

The adsorption of Fluorouracil on C_{82} and Si_{82} nanocages is investigated by theoretical methods. The main parameters of adsorption of C_{82}, Si_{82}, Ti-C_{82} and Ti-Si_{82} nanocages on Fluorouracil are calculated. The Si_{82} has higher ability to adsorb the Fluorouracil than C_{82}. Energy of adoption ($E_{adoption}$), cohesive energy, HOMO-LUMO energy difference, Gibbs free energy (ΔG) and recovery time (τ) values of Fluorouracil-nanocage complexes are calculated. The τ index of Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil are higher than C_{82}-Fluorouracil and Si_{82}-Fluorouracil. Ti adoption of Ti-C_{82} and Ti-Si_{82} can improve the adsorption of C_{82} and Si_{82} with Fluorouracil. Finally, the Ti-Si_{82} is acceptable nanocage to deliver and adsorb the Fluorouracil with high performance.

1. Introduction

In recent years, cancer is one of the leading causes of human mortality in developed countries and Fluorouracil is important drug to cancer treat [1–3]. When this drug is injected into a cancer patient, the active ingredients of the drug react with DNA and prevent the growth and development of cancer cells inside the body [4–6].

The metal doped materials with high thermodynamic stability, structural and high-temperature stability [7–9], hydrophobic properties to drugs [10–12] and acceptable physical and chemical forms [13–15] are potential candidates to carry and transfer of various types of cancer drugs [16,17].

In this study, the carbon and silicon atoms of C_{82} and Si_{82} nanocages are replaced with Ti atoms and the Ti-C_{82} and Ti-Si_{82} nanocages are produced. The electrons in orbitals of d of Ti have high potential to interaction with electrons of orbitals of p, d of carbon and silicon. These acceptable interactions between the Ti and C and Si atom in Ti-C_{82} and Ti-Si_{82} nanocages can increase the potential of nanocages to deliver of Fluorouracil, significantly.

Bautista et al [18] investigated the potential of boron nitride nanostructures to adsorb the acetylsalicylic acid by theoretical models. Their results demonstrated that boron nitride nanostructures can adsorb the acetylsalicylic acid with physical interaction [18].

Shakerzadeh et al [19] studied the fluorouracil interactions and adsorption by boron nitride nanomaterials. They show that boron nitride nanocages have valuable interactions with fluorouracil as well as BN nanostructures [19].

Gholami et al [20] investigated the abilities of BN fullerenes to deliver the hydroxyurea drugs. Their data indicated that the hydroxyurea and nitrosourea drugs have significant interaction with BN fullerenes in gas phase and water [20].

Anota et al. [21] studied the potential of some types of nanomaterials for drug delivery of anti-cancer Lapachone drug by calculation methods. They indicated that the studied drugs inside of nanomaterials can

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https://doi.org/10.1016/j.inoche.2023.111115
Received 7 June 2023; Received in revised form 12 July 2023; Accepted 20 July 2023
Available online 22 July 2023

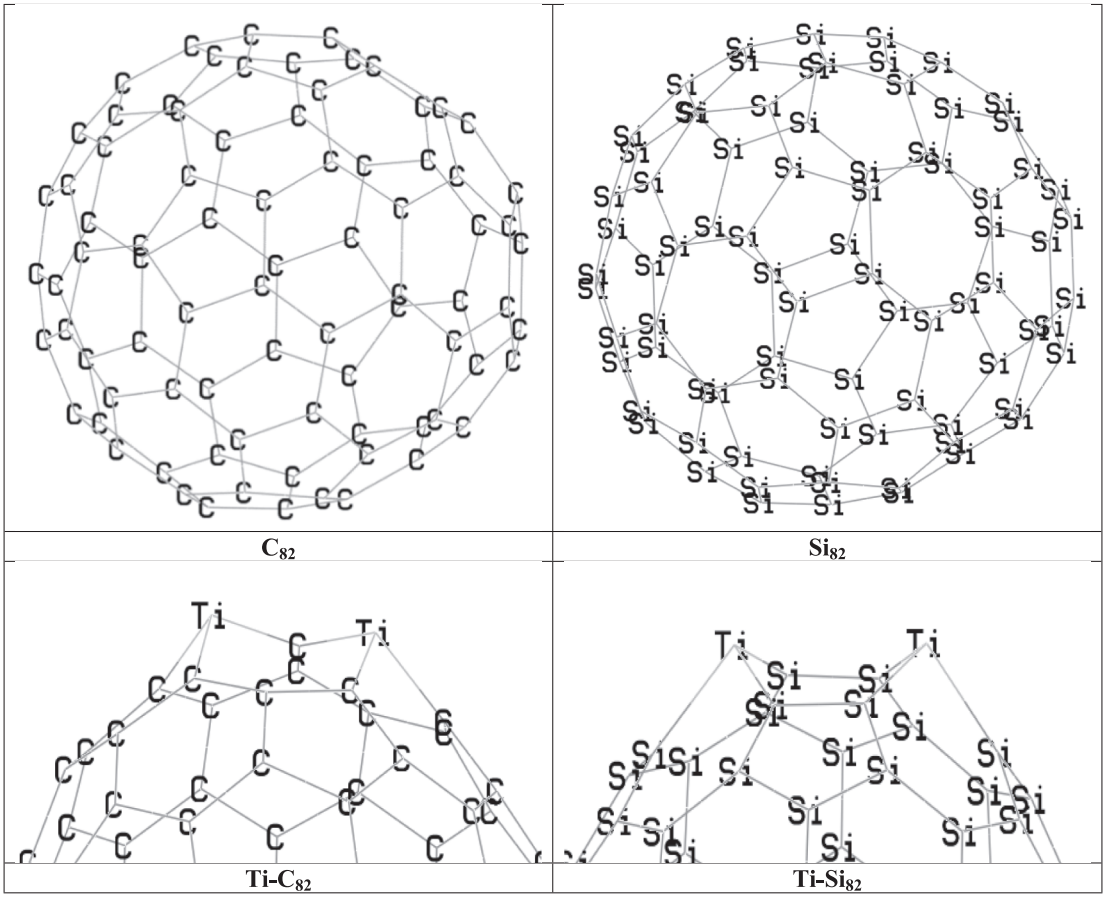

Fig. 1. Structures of C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} nanocages.

improve the adsorption abilities of fullerene to deliver the anti-cancer Lapachone drug, significantly [21].

Here, properties of Ti doped carbon (Ti-C_{82}) and Ti doped silicon (Ti-Si_{82}) nanostructures as drug carriers are examined by computational methods. The structural and electronic properties of nanocages and their complexes with Fluorouracil are examined. The important parameters for Fluorouracil-nanocages are examined to find the best carriers of anticancer drugs.

2. Computational details

Structures of nanocages (C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82}) and their complexes with Fluorouracil (C_{82}-Fluorouracil, Si_{82}-Fluorouracil, Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil) are optimized by PW91PW91 and M06-2X in GAMESS software [22–24].

The optimized material frequencies (C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82}) and complexes (C_{82}-Fluorouracil, Si_{82}-Fluorouracil, Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil) are examined in order to demonstrate that complexes are stable structures and complexes and they have the minimum energy, from thermodynamic view point [22–24].

Table 1
The $E_{adoption}$, $E_{HOMO\text{-}LUMO}$ and $E_{cohesive}$ in eV of nanocages.

	PW91PW91/6-311+G (2d, 2p)			M06-2X/cc-pVQZ		
Nanocages	$E_{adoption}$	$E_{HOMO\text{-}LUMO}$	$E_{cohesive}$	$E_{adoption}$	$E_{HOMO\text{-}LUMO}$	$E_{cohesive}$
C_{82}	–	2.51	−7.67	–	2.54	−7.60
Si_{82}	–	2.18	−7.98	–	2.21	−7.91
Ti-C_{82}	−4.12	2.27	–	−4.06	2.32	–
Ti-Si_{82}	−4.23	2.00	–	−4.18	2.03	–

Convergence threshold of optimized nanocages and their complexes with Fluorouracil are 1.5×10^5 Hartree/Bohr and 6.0×10^{-5} Angstrom [22–24]. The 90 *k*-point is used to optimize the nanocages and their complexes with Fluorouracil [25–27].

In this study, the global charge for complexes of nanocages with Fluorouracil (C_{82}-Fluorouracil, Si_{82}-Fluorouracil, Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil) are calculated by Natural Bond Orbital (NBO) model [22–25]. Here, the all possible multiplicity values for studied nanocages (C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82}) and their complexes with Fluorouracil are considered and the structures with the minimum energy are used to calculated the related parameters of drug delivery of Fluorouracil with nanocages [25–27].

3. Results and discussions

3.1. C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} nanocages

The potential of C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} nanocages to deliver the Fluorouracil as anticancer drug are examined [28–30]. The optimized structures of C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} and Fluorouracil are presented in Fig. 1.

Properties of Ti doped carbon (Ti-C_{82}) and Ti doped silicon (Ti-Si_{82}) nanostructures as drug carriers are examined by computational methods. The structural and electronic properties of nanocages and their complexes with Fluorouracil are examined. The important parameters for Fluorouracil-nanocages are examined to find the best carriers of anticancer drugs.

The metal doped nanostructures (Ti-doped nanocages) with high thermodynamic stability, structural and high-temperature stability, hydrophobic properties, suitable sensitivity to drugs, unique globular shape and acceptable physical and chemical forms are potential

Table 2
The data of Fluorouracil on surfaces of nanocages in gas phase.

PW91PW91/6-311+G (2d, 2p)				
Complexes	**$\Delta G_{adsorption}$**	**$E_{HOMO-LUMO}$**	**q (*e*)**	**τ (sec)**
a	−2.75	3.52	0.359	43.85
c	−2.87	3.23	0.377	46.51
e	−3.41	3.31	0.435	49.34
g	−3.49	3.03	0.455	53.32
b	−2.70	3.56	0.354	42.97
d	−2.81	3.27	0.372	45.58
f	−3.34	3.36	0.430	48.35
h	−3.42	3.08	0.451	52.25
M06-2X/cc-pVQZ				
Complexes	**$\Delta G_{adsorption}$**	**$E_{HOMO-LUMO}$**	**q (*e*)**	**τ (sec)**
a	−2.67	3.63	0.341	41.66
c	−2.78	3.33	0.358	44.18
e	−3.31	3.41	0.413	46.87
g	−3.39	3.12	0.432	50.65
b	−2.62	3.68	0.338	40.83
d	−2.72	3.37	0.354	43.30
f	−3.24	3.44	0.408	45.93
h	−3.32	3.16	0.428	49.64

candidates to carry and transfer of various types of cancer drugs. In this study, the carbon and silicon atoms of C_{82} and Si_{82} nanocages are replaced with Ti atoms and the Ti-C_{82} and Ti-Si_{82} nanocages are produced. The electrons in orbitals of d of Ti have high potential to interaction with electrons of orbitals of p, d of carbon and silicon. These acceptable interactions between the Ti and C and Si atom in Ti-C_{82} and Ti-Si_{82} nanocages can increase the potential of nanocages to deliver of Fluorouracil, significantly.

The adoption energy ($E_{adoption}$), cohesive energy, HOMO-LUMO energy difference, Gibbs free energy (ΔG) and recovery time (τ) values (Tables 1 and 2) are calculated [31–33] as following:

$$E_{adoption} = E_{Ti-nanocage} - E_{nanocage} - E_{Ti} \quad (1)$$

$$E_{cohesive} = \left(E_{nanocage} - 82{*}E_{carbonatom}\right)/82 \quad (2)$$

$$E_{HOMO-LUMO} = E_{LUMO} - E_{HOMO} \quad (3)$$

$$\Delta G_{adsorption} = G_{Fluorouracil-nanocage} - \left(G_{nanocage} + G_{Fluorouracil}\right) \quad (4)$$

$$\tau = (1/\vartheta){*}\exp\left(-E_{adsorption}/KT\right) \quad (5)$$

Results indicated that the $E_{adoption}$ of Ti-C_{82} are negative values. The Ti-C and Ti-Si bonds in Ti-C_{82} and Ti-Si_{82} nanocages are strong [34–37]. Results shown that the negative values of $E_{cohesive}$ can demonstrate the C_{82} and Si_{82} structures have suitable structural stability and thermodynamic stability [38–41].

3.2. Complexes of Fluorouracil with C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} nanocages

The possible positions for adsorption of Fluorouracil on nanocages are presented in Figs. 2 and 3. The Fluorouracil are interacted with Ti atoms of nanocages. The calculated $E_{HOMO-LUMO}$, q, τ index and

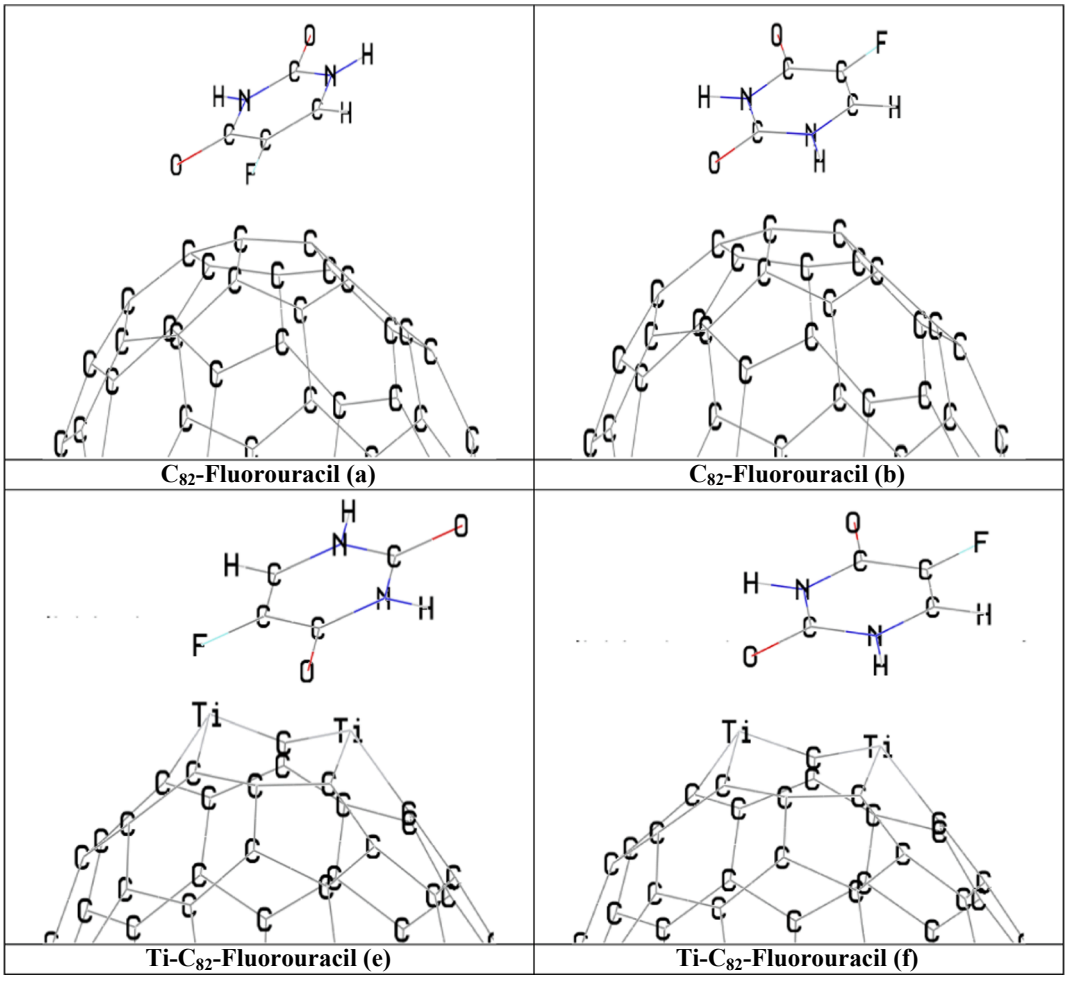

Fig. 2. Complexes of of C_{82} and Ti-C_{82} with Fluorouracil.

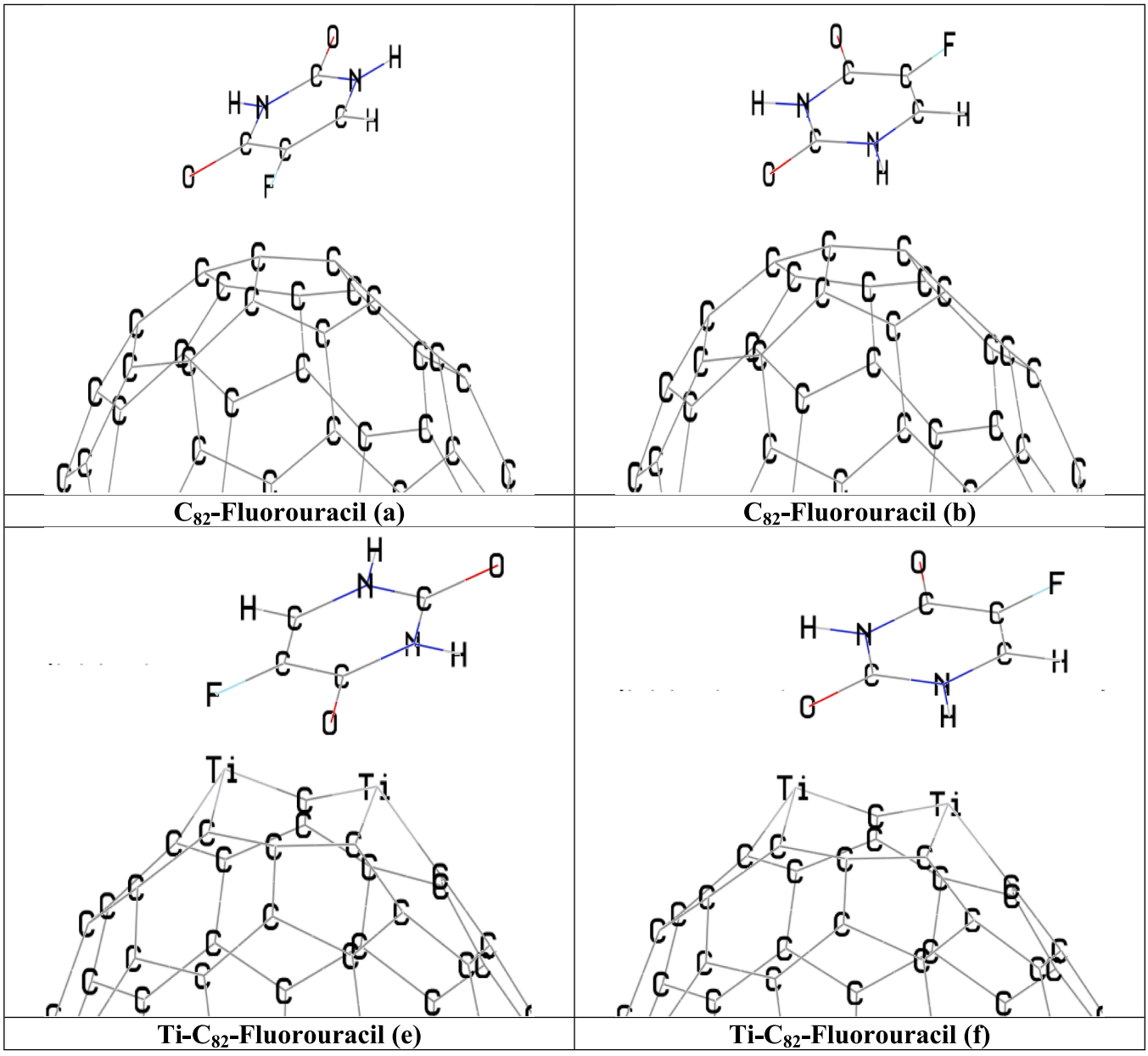

Fig. 3. Complexes of Si_{82} and Ti-Si_{82} with Fluorouracil.

$\Delta G_{adsorption}$ (Table 2) of nanoacge-Fluorouracil complexes are calculated.

Properties of Ti doped carbon (Ti-C_{82}) and Ti doped silicon (Ti-Si_{82}) nanostructures as drug carriers are examined by computational methods. The structural and electronic properties of nanocages and their complexes with Fluorouracil are examined. The important parameters for Fluorouracil-nanocages are examined to find the best carriers of anticancer drugs.

The $\Delta G_{adsorption}$ are negative and Fluorouracil adsorption on C_{82}, Si_{82}, Ti-C_{82}, Ti-Si_{82} are exothermic reactions. The metal adoption of nanocage can improve the potential of nanocage to adsorb the Fluorouracil. The Si nanocage has higher ability to adsorb the Fluorouracil than C nanocage [42–45].

The τ index of Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil are higher than C_{82}-Fluorouracil and Si_{82}-Fluorouracil. The τ index of Ti-Si_{82}-Fluorouracil are higher than Ti-C_{82}-Fluorouracil. The τ index of Si_{82}-Fluorouracil is bigger than C_{82}-Fluorouracil.

In water, $\Delta G_{adsorption}$ values (Table 3) are negative and the interactions of Fluorouracil with C_{82}, Si_{82}, Ti-C_{82} and Ti-Si_{82} nanocages are exothermic reactions. The water is improved the adsorption of Fluorouracil on nanocages and $E_{adsorption}$ and $\Delta G_{adsorption}$ are acceptable values [46–48].

The τ index of Ti-Si_{82}-Fluorouracil are higher than Ti-C_{82}-Fluorouracil [49,50]. Finally, Ti-Si_{82} and Ti-C_{82} have high potential to adsorb

Table 3
The data of Fluorouracil on surfaces of nanocages in water.

Complexes	$\Delta G_{adsorption}$	$E_{HOMO-LUMO}$	q (*e*)	τ (sec)
a	−2.83	3.41	0.377	46.04
c	−2.96	3.13	0.396	48.84
e	−3.50	3.21	0.457	51.81
g	−3.58	2.94	0.478	55.99
b	−2.77	3.45	0.372	45.12
d	−2.90	3.17	0.393	47.86
f	−3.43	3.24	0.451	50.77
h	−3.51	2.99	0.472	54.87

the Fluorouracil.

4. Conclusions

The adoption energy ($E_{adoption}$), cohesive energy, HOMO-LUMO energy difference, Gibbs free energy (ΔG) and recovery time (τ) values of complexes of Fluorouracil-nanocages are calculated. The calculated $\Delta G_{adsorption}$ of nanocages-Fluorouracil are negative and these processes are exothermic reactions. The τ of Ti-C_{82}-Fluorouracil and Ti-Si_{82}-Fluorouracil are higher than C_{82}-Fluorouracil and Si_{82}-Fluorouracil. The main parameters of interactions of C_{82}, Si_{82}, Ti-C_{82} and Ti-Si_{82} nanocages with Fluorouracil are calculated. The Si_{82} has higher ability to adsorb the Fluorouracil than C_{82}. The τ index of Ti-Si_{82}-Fluorouracil are higher than Ti-C_{82}-Fluorouracil. The Ti-Si_{82} is valuable material to adsorb the Fluorouracil from theoretical viewpoint.

CRediT authorship contribution statement

Ali Jihad: Conceptualization, Methodology. **Jamal A. Aljabbar Attawi:** Software, Validation. **Uday Abdul-Reda Hussein:** Data curation, Writing – original draft. **Muhja Ahmed:** Writing – review & editing, Visualization. **Ahmad Ismael Saber:** Formal analysis, Methodology. **Sarah A. Hamood:** Investigation, Resources, Visualization. **Benien M. Ridha:** Software, Validation. **Ali H. Alsalamy:** Data curation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

We thank our university for their computational supports.

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