

# Kinetic Study of Reactions between Nitrile Oxides with Simple Cycloalkynes with DFT Method

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**ABSTRACT:** In this study, reactions of the simple cycloalkynes with substituted Nitrile Oxides, by DFT method will be discussed. The investigation of the structural properties, theoretical thermodynamic and kinetic data, i.e., the activation free energies ( $\Delta G^*$ ), the free energies changes of reaction ( $\Delta_r G$ ) and rate constants of the reactions ( $k$ ) in 298 K and effects of Electron-withdrawing and electron-donating groups on the interaction of the LUMO with the HOMO of the dipole and dipolarophile will be presented. The results show an increase in the HOMO-LUMO energy gaps ( $\Delta E$ ) &  $\Delta G^*$  also decreasing the  $\Delta_r G$  &  $k$  by increasing the ring size of cycloalkynes.

**KEYWORDS:** Substituted Nitrile oxide; HOMO-LUMO gap; DFT-B3LYP molecular orbital calculations; Cycloalkyne.

## INTRODUCTION

In organic chemistry, Diels–Alder and 1,3-dipolar cycloaddition reactions are powerful methods for the construction of six- and five-membered rings [1]. Amongst these, cycloaddition reactions of nitrosoalkenes [2] azoalkenes [3] and nitrile oxides [4] are important tools for the synthesis of heterocyclic compounds containing nitrogen, such 1,2-oxazines, pyridazines and isoxazolines. The 1,3-dipolar cycloaddition, is the organic chemical reaction belonging to the larger class of cycloaddition reactions [5,6]. It is the reaction between a 1,3-dipole with 4 electrons and a dipolarophile with 2 electrons, most of which are substituted alkenes to form a 5-membered ring. These compounds participate in a concerted, pericyclic shift. A condition for such a reaction to take place is a certain similarity of the interacting HOMO and LUMO orbitals, depending on the relative orbital energies of both the dipolarophile

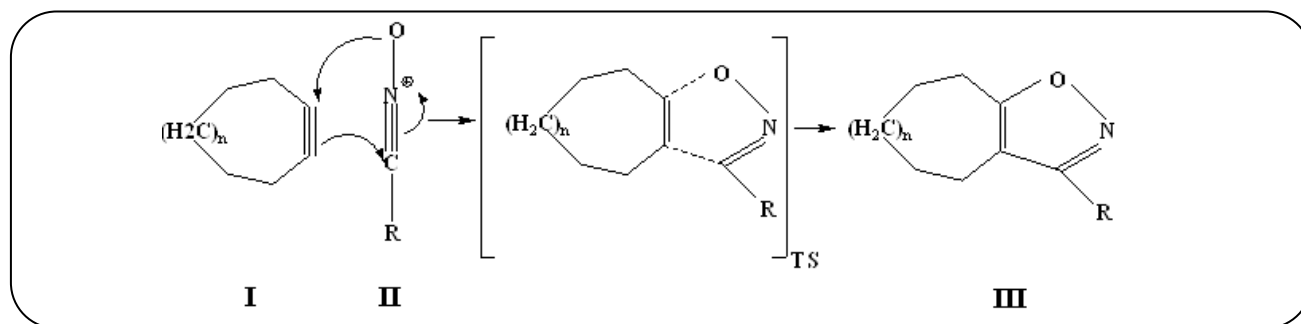
and the dipole. Nitrile oxides are referred to as a HOMO-LUMO controlled dipole or an ambiphilic dipole [7]. HOMO of dipole can pair with LUMO of dipolarophile; alternatively, HOMO of dipolarophile can pair with LUMO of the dipole. A substituent on the dipolarophile or dipole would accelerate the reaction by lowering the energy gap between the two interacting orbitals. i.e., an electron-withdrawing groups would lower LUMO while an electron-donating groups would raise the HOMO [5-19]. The [3+2] cycloaddition reaction of nitrile oxides is a  $6\pi$  e- concerted reaction that occurs in situ during the preparation of these reactive species. Nitrile oxides are generally not isolable. The isoxazoline product of a nitrile oxide cycloaddition can be reduced under mild conditions to afford an “aldol type” product. Nitrile oxides maybe generated by chlorination of an aldoxime or by activation of an aliphatic nitro compound. 1,3-dipolar cycloaddition

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1021-9986/2019/5/99-110

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Scheme 1: The Huisgen 1,3-dipolar cycloaddition of cycloalkynes ( $n=1-4$ ) and Nitrile Oxide.

with nitrile oxides is a widely used masked-aldol reaction. Cycloaddition between a nitrile oxide and an alkene yields the cyclic isoxazoline product, whereas the reaction with an alkyne yields the isoxazole. Both isoxazolines and isoxazoles can be cleaved by hydrogenation to reveal aldol-type  $\beta$ -hydroxycarbonyl or Claisen-type  $\beta$ -dicarbonyl products, respectively [20]. The strain energy in simple cycloalkynes may be increased by bending the normally linear triple bond. The strain energy and reactivity in the cycloalkynes increase as the size of the ring decreases [21-27]. The strain energies of  $C_7$  to  $C_{10}$  are 10.1, 9.5, 8.3, and 7.8 kcal/mol, respectively [26]. We worked on Cycloadditions of 1,3-dipolar of substituted Nitrile Oxides(II) ( $R-CNO$ ,  $R = H, CH_3, Ph$  and  $Ph(CH_3)_3$ ) with simple cycloalkynes (I). These reactions may occur by the concerted mechanism of 1,3-dipolar cycloaddition to produce Nitrile Oxides heterocycles (III). See Scheme 1.

#### COMPUTATION DETAILS AND CALCULATIONS

The DFT-B3LYP molecular orbital calculations were performed with the Gaussian 03 program [28]. Geometries for all structures were fully optimized using analytical energy gradients in B3LYP levels with the 6-31G\* basis sets. The Synchronous Transit-Guided Quasi-Newton (STQN) method is used to located transition states, which were confirmed to have one imaginary frequency. The frequencies were scaled by a factor of 0.8929 and used to compute the activation free energies ( $\Delta G^*$ ) and the free energies changes of reaction ( $\Delta_r G$ ) at 298 K. Also, rate constants were calculated with the Eyring equation, derived from transition state theory [29].

In this study, the most stable conformations of the simple cycloalkynes ( $C_7-C_{10}$ ) were investigated in the

1,3-dipolar cycloaddition reactions with  $R-CNO$  ( $R = H, CH_3, Ph$  and  $Ph(CH_3)_3$ ).

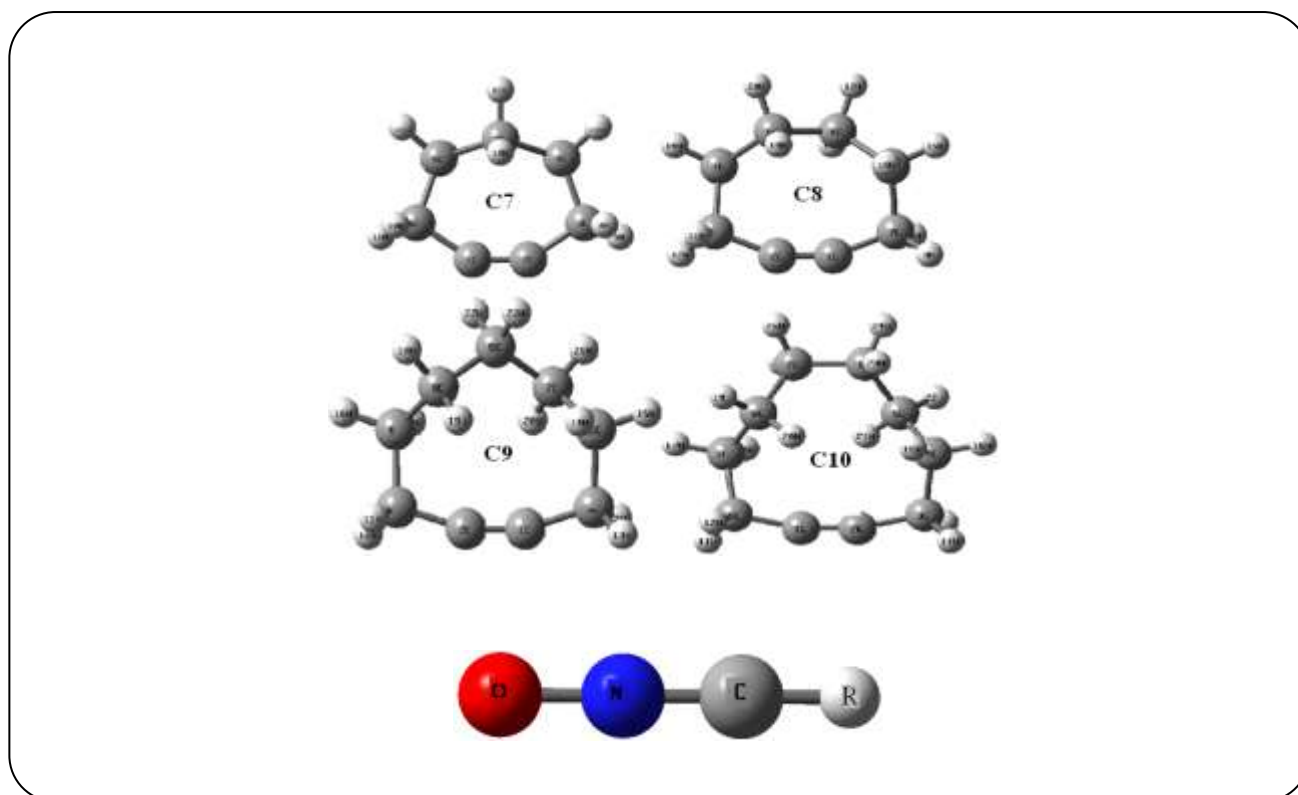
#### RESULTS AND DISCUSSION

The key structural parameters, for cycloalkynes, nitrile oxides, products, and transition states are recorded in Tables 1-3. The energy surfaces and the barrier energies for the reactions were investigated in detail by changing the position and distances between appropriate atoms in the reaction pathway. The synchronous transition states structures are obtained with mean bond length values of  $C1-C2$  and  $C3-O5$  bonds in transition states of  $C_7, C_8, C_9$ , and  $C_{10}$  with  $R-CNO$ . The bond length values of  $C1-C2$  and  $C3-O5$  for the transition states (TS) in  $\text{Å}^\circ$  for 1,3-dipolar cycloaddition reactions of cycloalkynes ( $C_7-C_{10}$ ) and substituted nitrile oxides are: (a) for  $H-CNO$  reaction with  $C_7$  to  $C_{10}$  [2.52, 2.42], [2.34, 2.50], [2.24, 2.47], and [2.21, 2.54]; (b) for  $CH_3-CNO$  reaction with  $C_7$  to  $C_{10}$  [2.34, 2.50], [2.36, 2.40], [2.28, 2.36], and [2.25, 2.38]; (c)  $Ph-CNO$  reaction with  $C_7$  to  $C_{10}$  [2.52, 2.42], [2.38, 2.36], [2.31, 2.30], and [2.27, 2.33], and (d) for  $Ph(CH_3)_3-CNO$  reaction with  $C_7$  to  $C_{10}$  [2.49, 2.39], [2.36, 2.33], [2.31, 2.30] and [2.26, 2.30] respectively. As seen, the value of the new bonds formed in transition states during cycloaddition reactions is not the same due to the asymmetry of the links. The optimized structures show for reactants, transition states, and Products in Fig. 1-3. The diagram of the activation free energies ( $\Delta G^*$ ) and the free energies changes of reaction ( $\Delta_r G$ ) at 298 K for 1,3-dipolar cycloaddition reactions were shown in Fig. 4.

The results indicate that thermodynamic stability increases with increasing the ring size of cycloalkynes, therefore decrease the free energies change between reactants and products ( $\Delta_r G$ ). The free energies changes

Table 1: The selected structural parameters of Nitrile Oxides.

parameters	R-CNO			
	HCNO	CH <sub>3</sub> CNO	PhCNS	Ph(CH <sub>3</sub> ) <sub>3</sub> CNO
(°A) Bond length				
O2-N1	1.21	1.21	1.2	1.22
N1-C3	1.15	1.15	1.15	1.15
C3-C4	-	1.21	1.54	1.42
C4-C5	-	-	1.39	1.41
C4-C9	-	-	1.39	1.41
C5-C6	-	-	119.99	1.39
C9-C8	-	-	1.39	1.39
(°) Bond length				
O2-N1-C3	179.97	179.99	180	179.99
N1-C3-H4	179.96	-	-	-
N1-C3-C4	-	179.97	179.97	179.96
C3-C4-C5	-	-	119.99	119.06
C3-C4-C9	-	-	120.1	119.45
C4-C5-C12	-	-	-	120.53
C4-C9-C16	-	-	-	120.86

Fig 1: Cycloalkynes (C7-C10) & Nitrile Oxides (R= H, CH<sub>3</sub>, Ph & Ph(CH<sub>3</sub>)<sub>3</sub>).

**Table 2: The selected structural parameters of the cycloalkynes.**

parameters	C <sub>7</sub>	C <sub>8</sub>	C <sub>9</sub>	C <sub>10</sub>
Bond length) °A(				
C1-C2	1.21	1.21	1.21	1.21
C2-C3	1.46	1.46	1.46	1.46
C3-C4	1.55	1.55	1.55	1.55
C5-C6	1.55	1.56	1.55	1.55
C1-C5	1.47	-	1.46	-
C1-C7	-	1.46	-	-
C1-C9	-	-	-	1.46
Bond angle) (°				
C1-C2-C3	146.00	157.46	162.86	166.99
C2-C3-C4	104.33	106.33	107.30	107.78
C2-C1-C9	-	-	-	165.39
C2-C1-C5	144.80	-	161.49	-
C7-C1-C2	-	106.32	-	-
C1-C9-C10	-	-	-	107.95
C1-C7-C8	-	106.30	-	-
C2-C3-H13	-	-	-	110.79
C2-C3-H11	-	110.35	110.59	-
C2-C3-H14	-	-	-	112.08
C2-C3-H10	-	-	112.40	-
C2-C3-H12	-	113.73	-	-
C1-C9-H11	-	-	-	111.97
C1-C5-H9	-	-	112.25	-
C1-C7-H9	-	113.72	-	-
C1-C5-H11	114.5	-	-	-

**Table 3: The structural parameters of the Reactants, Transition States and Products of reaction of Cycloalkynes (C<sub>7</sub>-C<sub>10</sub>) and Nitrile Oxides.**

parameters	C <sub>7</sub>								C <sub>8</sub>							
	H-CNO		CH <sub>3</sub> -CNO		Ph-CNO		Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO		H-CNO		CH <sub>3</sub> -CNO		Ph-CNO		Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO	
	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod
Bond lengths																
C2-C3	1.22	1.37	1.23	1.37	1.23	1.37	1.23	1.37	1.23	1.37	1.23	1.37	1.23	1.37	1.23	1.37
C3-C4	1.46	1.49	1.46	1.49	1.46	1.49	1.46	1.49	1.46	1.49	1.46	1.49	1.46	1.49	1.46	1.49
C1-C2	2.52	1.42	2.34	1.43	2.52	1.43	2.49	1.43	2.34	1.42	2.36	1.43	2.38	1.44	2.36	1.44
C3-O5	2.42	1.35	2.50	1.35	2.42	1.35	2.39	1.35	2.50	1.35	2.40	1.35	2.36	1.35	2.33	1.35
C1-N9	1.19	1.31	1.29	1.31	1.19	1.32	1.19	1.31	1.19	1.31	1.19	1.31	1.20	1.31	1.20	1.31
N9-O5	1.22	1.40	1.19	1.40	1.22	1.39	1.21	1.40	1.21	1.39	1.22	1.40	1.22	1.39	1.23	1.39
Bond angles																
C1-N9-O5	152.96	104.55	152.60	105.45	151.62	105.48	150.31	105.45	147.34	104.36	146.68	109.18	145.37	105.60	144.13	105.42
H21-C1-N9	148.24	118.72	-	-	-	-	-	-	139.71	119.01	-	-	-	-	-	-
C21-C1-N9	-	-	150.41	119.70	148.24	118.87	153.32	120.30	-	-	145.92	119.85	144.35	118.71	148.50	120.23
C3-O5-N9	90.05	109.57	90.54	109.31	92.99	109.67	93.73	109.37	90.50	110.21	92.63	92.03	94.41	109.88	94.91	110.04
C2-C1-N9	91.48	113.31	89.80	112.15	89.51	111.83	89.97	112.13	96.54	113.49	94.42	112.06	93.86	111.97	94.28	112.08
C2-C3-O5	101.86	109.72	103.43	109.72	103.85	109.63	103.82	109.66	100.96	109.23	102.21	122.80	104.06	109.53	103.42	109.40
C3-C2-C1	103.63	102.76	102.50	103.28	102.01	103.32	102.16	103.29	104.64	102.63	104.04	103.15	102.13	102.93	103.25	102.97
C2-C1-H21	126.03	127.92	-	-	-	-	-	-	123.74	127.46	-	-	-	-	-	-
C2-C1-C21	-	-	119.78	128.11	121.80	129.26	116.69	127.51	-	-	119.65	128.04	121.06	129.25	117.20	127.64
C4-C3-O5	110.12	117.35	107.84	117.84	107.22	116.83	107.71	117.32	99.55	114.98	98.62	101.35	97.79	114.55	98.46	114.69
C2-C3-C4	142.03	132.84	148.68	148.68	148.91	133.44	148.38	132.93	159.47	135.71	158.30	135.82	158.03	135.84	158.09	135.82

Table 3: The structural parameters of the Reactants, Transition States and Products of reaction of... (Continued)

parameters	C <sub>7</sub>								C <sub>8</sub>							
	H-CNO		CH <sub>3</sub> -CNO		Ph-CNO		Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO		H-CNO		CH <sub>3</sub> -CNO		Ph-CNO		Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO	
	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod	[TS]	Prod
Bond lengths																
C2-C3	1.23	1.37	1.23	1.37	1.24	1.37	1.24	1.37	1.27	1.37	1.26	1.36	1.24	1.37	1.24	1.37
C3-C4	1.48	1.49	1.48	1.49	1.48	1.49	1.47	1.49	1.42	1.49	1.44	1.50	1.47	1.50	1.47	1.49
C1-C2	2.24	1.42	2.28	1.43	2.31	1.44	2.31	1.43	2.20	1.42	2.25	1.43	2.26	1.44	2.25	1.43
C3-O5	2.47	1.35	2.36	1.35	2.30	1.35	2.30	1.35	2.56	1.35	2.41	1.35	2.31	1.35	2.29	1.35
C1-N9	1.20	1.31	1.20	1.31	1.21	1.31	1.21	1.31	1.20	1.31	1.20	1.31	1.21	1.32	1.21	1.31
N9-O5	1.21	1.39	1.22	1.40	1.22	1.21	1.23	1.39	1.22	1.39	1.23	1.39	1.22	1.38	1.23	1.40
Bond angles																
C1-N9-O5	144.31	104.38	143.45	105.11	141.5	105.60	141.07	105.25	143.22	104.53	141.89	105.40	140.30	105.92	139.28	105.20
H30-C1-N9	138.33	119.01	-	-	-	-	-	-	137.87	118.75	-	-	-	-	-	-
C30-C1-N9	-	-	143.17	119.43	143.9	118.71	145.62	120.08	-	-	141.66	119.70	140.60	117.70	143.58	119.86
C3-O5-N9	90.44	110.19	93.75	109.70	95.81	109.88	96.16	109.76	89.37	110.21	93.66	109.64	95.70	110.00	96.44	109.80
C2-C1-N9	99.25	113.43	96.24	112.28	96.12	111.85	96.07	112.13	101.56	113.31	97.80	109.51	97.17	111.32	97.55	112.33
C2-C3-O5	100.37	109.23	101.81	109.46	103.54	109.53	103.32	109.60	98.85	109.14	100.82	109.50	102.70	109.48	101.96	109.28
C3-C2-C1	105.49	102.64	104.64	103.19	102.93	102.97	103.37	103.22	106.92	102.78	105.76	103.43	203.81	103.19	104.74	103.29
C2-C1-H30	122.31	127.47	-	-	-	-	-	-	120.55	127.84	-	-	-	-	-	-
C2-C1-C30	-	-	120.53	128.08	119.80	129.30	118.30	127.75	-	-	120.53	128.31	121.55	130.78	118.85	127.76
C4-C3-O5	94.96	114.98	94.83	114.69	94.98	114.55	163.09	113.96	89.70	115.77	89.46	115.15	89.65	114.23	90.00	115.33
C2-C3-C4	163.62	135.71	163.32	135.76	161.4	135.84	163.57	136.29	171.00	135.07	169.36	135.26	167.42	136.03	167.73	135.30

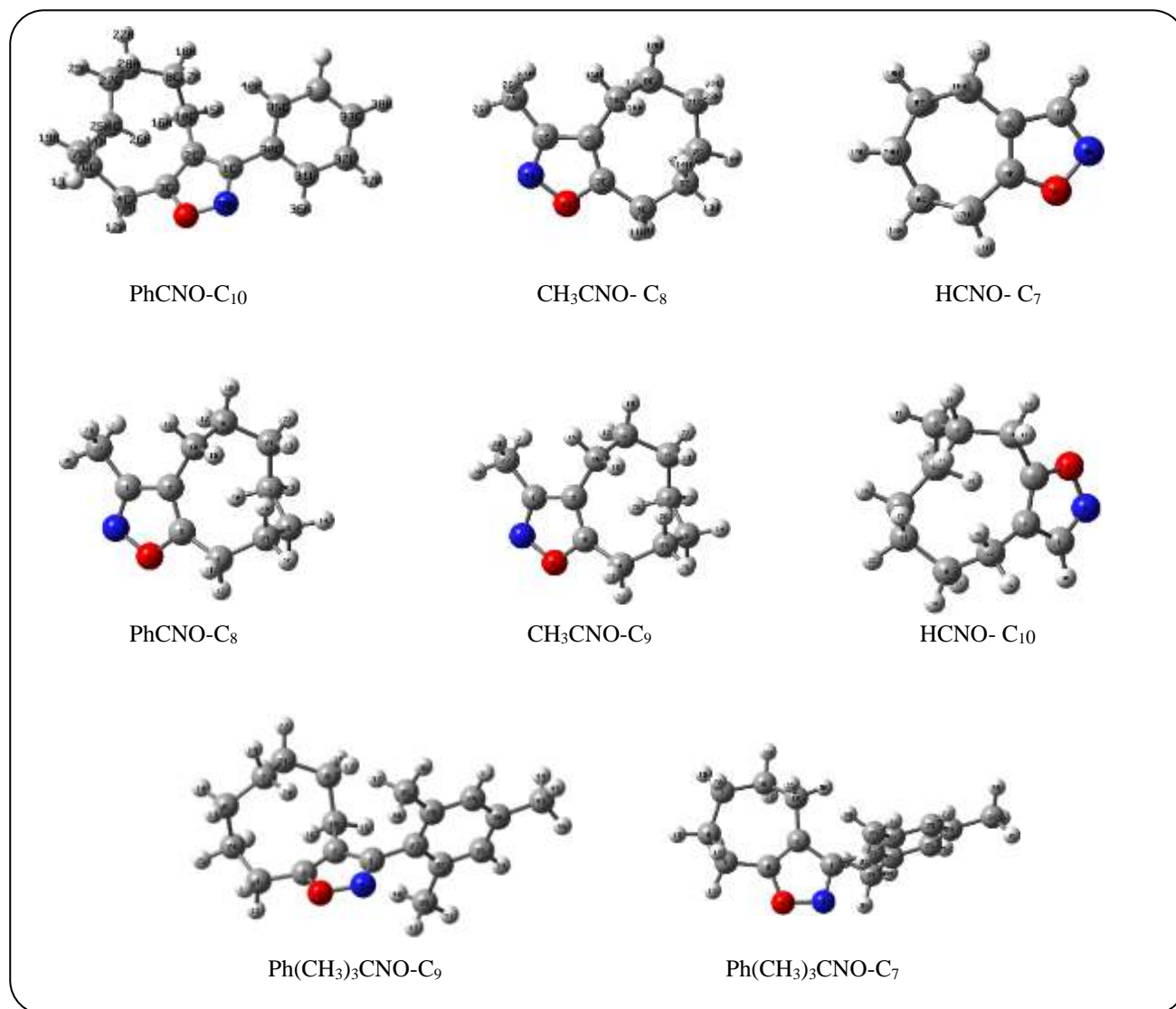


Fig. 2: Some of the products of the structure of Nitrile Oxide – Cycloalkyne.

of reactions ( $\Delta_r G$ ) were shown in Table 4. The values of  $\Delta_r G$  for the exothermic reactions of R–CNO with C<sub>7</sub> to C<sub>10</sub> are respectively : for R = H; -89.46, -74.86, -69.12 and -68.15 kcal/mol, for R = CH<sub>3</sub>; -83.51, 20.05, 22.9 and 23.11 kcal/mol, for R = Ph; 11.56, 18.51, 19.24 and 19.53 kcal/mol, and for R=Ph(CH<sub>3</sub>)<sub>3</sub>: -74.91, -62.79, -56.43 and -54.49 respectively. The gap of the free energies between reactants and products has displayed a decrease in the thermodynamic stability of bigger cycloalkynes. See Fig. 4. The kinetic data, i.e., the activation free energies ( $\Delta G^*$ ), the rate constant of reaction ( $k$ ) and the relative rate constant ( $k^1$ ) were summarized in Table 4. The free energy differences between transition states and reactants ( $\Delta G^*$ ) for the

reactions of R–CNO with C<sub>7</sub> to C<sub>10</sub> are respectively are: for R = H; 12.10, 16.11, 18.01 and 18.22 kcal/mol, for R = CH<sub>3</sub>; 15.47, 20.05, 22.9 and 23.11 kcal/mol, for R = Ph; 11.56, 18.51, 19.84 and 19.53 kcal/mol, and for R=Ph(CH<sub>3</sub>)<sub>3</sub>: 14.83, 20.49, 23.67 and 23.83 respectively. The results show an increase in the  $\Delta G^*$  of the 1,3-dipolar cycloaddition reactions of C<sub>7</sub> to C<sub>10</sub> and R–CNO, by increasing the ring size and decreasing the strain energy of cycloalkynes. See Table 4 & Fig 5. The chemical reactivity and the calculated rate constants in the calculated method have increased by decreasing the ring size, bond angles of triple bonds, and increasing the strain energies of the cycloalkynes. The rate constants ( $k$ ) with B3LYP/6-31G\* for the reactions of R–CNO with C<sub>7</sub>

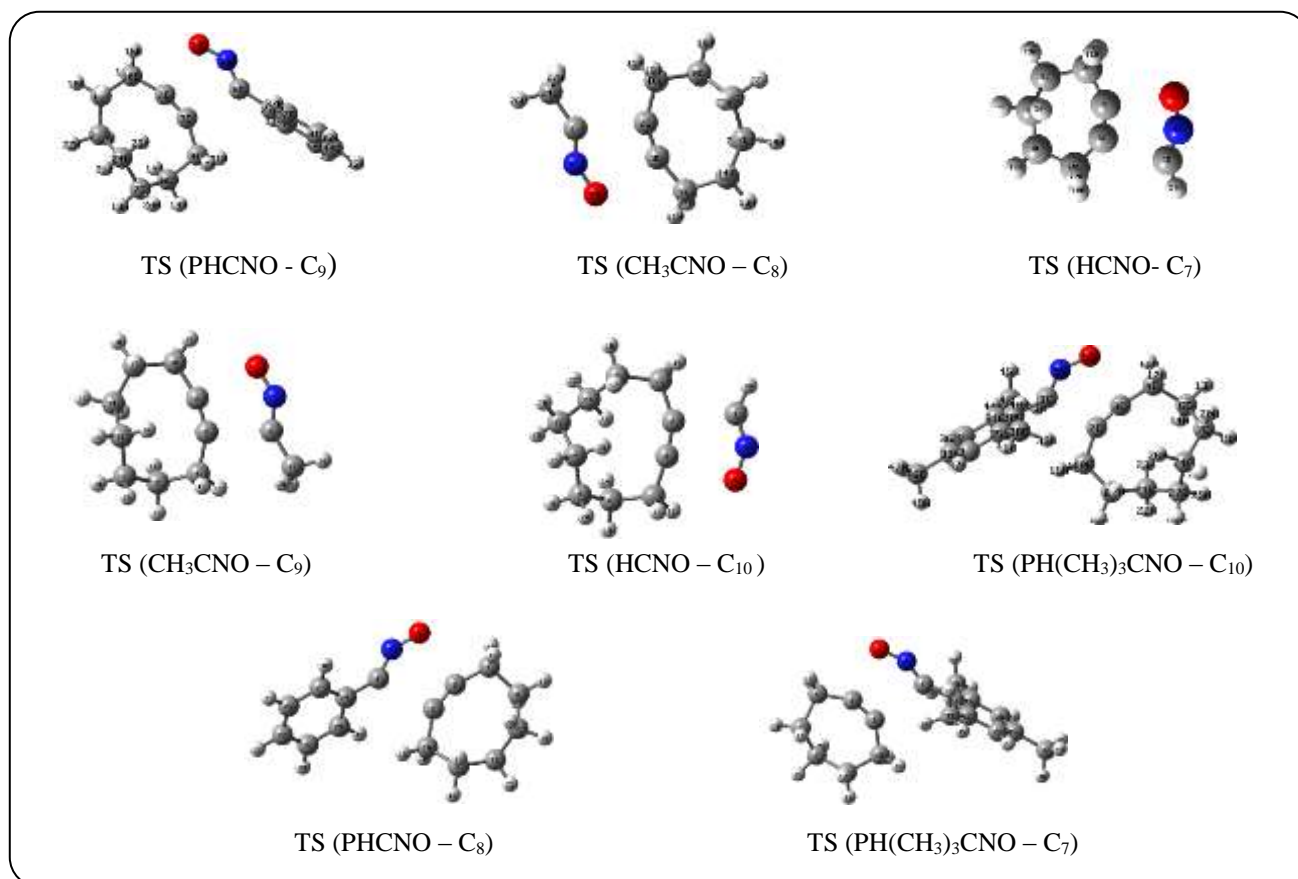


Fig. 3: Some of the structures transition states of Cycloalkyne- Nitrile Oxide.

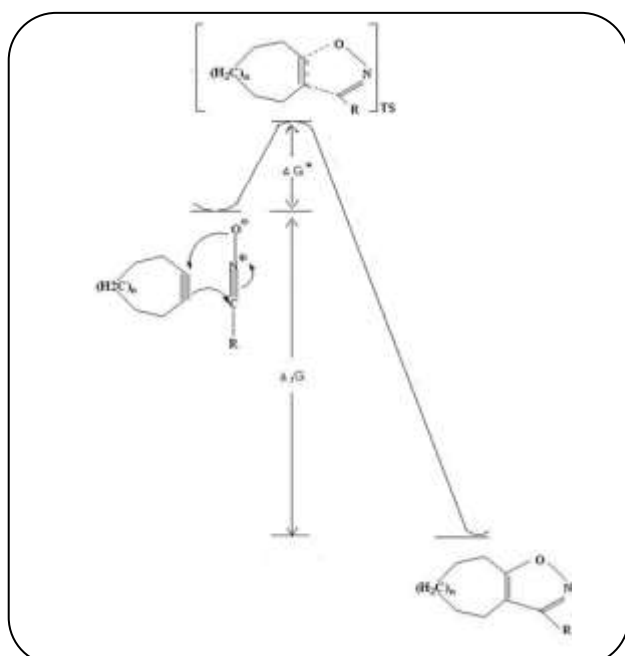


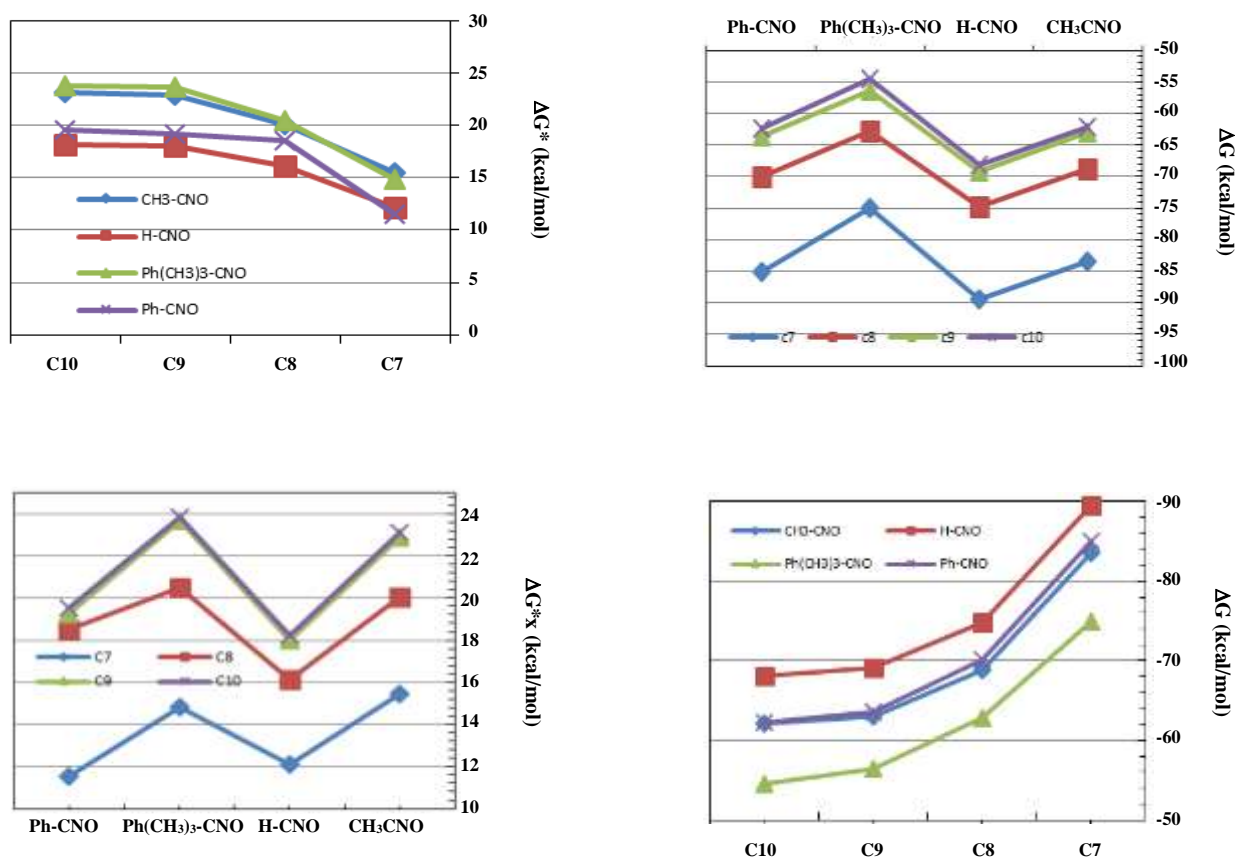
Fig. 4: The digram energy surfaces and the barrier energies of 1,3-dipolar cycloaddition reactions of cycloalkynes ( $n= 1-4$ ) with Nitrile Oxides ( $R-CNO$ ,  $R=H,CH_3,Ph,Ph(CH_3)_3$ ).

to C<sub>10</sub> are respectively: for R = H; 8326.82, 9.62, 0.39 and 0.27 M<sup>-1</sup>S<sup>-1</sup>, for R = CH<sub>3</sub>; 28.33, 1.24 x 10<sup>-2</sup>, 1.01 x 10<sup>-4</sup> and 7.10 x 10<sup>-5</sup> M<sup>-1</sup>S<sup>-1</sup>, for R = Ph; 20822.9, 1.67 x 10<sup>-1</sup>, 4.9 x 10<sup>-2</sup> and 2.99 x 10<sup>-2</sup> M<sup>-1</sup>S<sup>-1</sup>, and for R=Ph(CH<sub>3</sub>)<sub>3</sub>: 83.44, 5.92x 10<sup>-3</sup>, 2.76 x 10<sup>-5</sup> and 2.11x10<sup>-5</sup> M<sup>-1</sup>S<sup>-1</sup>. The relative constants of reaction rates increased by decreasing the size of the rings and increasing the strain energies and chemical affinity of cycloalkynes to take part in the 1,3-dipolar cycloaddition reactions. Two factors are the main motive forces of these results. Strain energy is one of the main functions of these reactions. By increasing the ring size of the cycloalkynes and decreasing the strain energy of the cycloalkynes C7 to C10, the internal bond angles of C-C≡C have increased. The bond angles of C1-C2≡C3 are 145.90, 157.56, 162.96, and 167.04 for C7 to C10, respectively. For participating in the cycloalkynes in these 1,3-dipolar cycloaddition reactions, the thermodynamic and kinetic stabilities of I are related to the strain energies and the structural characters particularly around the C-C≡C-C.



**Table 4: The free activation energies ( $\Delta G^*$ ), the free energies changes in reactions ( $\Delta_r G$ ) of Cycloalkynes with Nitrile Oxides in kcal / mol and rate constants in  $M^{-1}Sec^{-1}(k)$  and relative rate constants ( $k^I$ ).**

Nitrile Oxides→		H-CNO			CH <sub>3</sub> -CNO			
Cycloalkynes	$\Delta G^*$	$\Delta_r G$	k	k <sup>I</sup>	$\Delta G^*$	$\Delta_r G$	k	k <sup>I</sup>
C <sub>7</sub>	12.1	-89.46	8326.82	30501.18	15.47	-83.51	28.33	3990.01
C <sub>8</sub>	16.11	-74.86	9.62	35.24	20.05	-68.77	1.24 x 10 <sup>-2</sup>	174.65
C <sub>9</sub>	18.01	-69.12	0.39	1.42	22.9	-62.97	1.01 x 10 <sup>-4</sup>	1.42
C <sub>10</sub>	18.22	-68.15	0.27	1	23.11	-62.07	7.10 x 10 <sup>-5</sup>	1
Nitrile Oxides →		Ph-CNO			Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO			
Cycloalkynes	$\Delta G^*$	$\Delta_r G$	k	k <sup>I</sup>	$\Delta G^*$	$\Delta_r G$	k	k <sup>I</sup>
C <sub>7</sub>	11.56	-85.01	20822.9	696418.1	14.83	-74.91	83.44	3954502
C <sub>8</sub>	18.51	-70.08	0.1673	5.59	20.49	-62.79	5.92 x 10 <sup>-3</sup>	280.57
C <sub>9</sub>	19.24	-63.63	0.049	1.64	23.67	-56.43	2.76 x 10 <sup>-5</sup>	1.31
C <sub>10</sub>	19.53	-62.33	0.0299	1	23.83	-54.49	2.11 x 10 <sup>-5</sup>	1

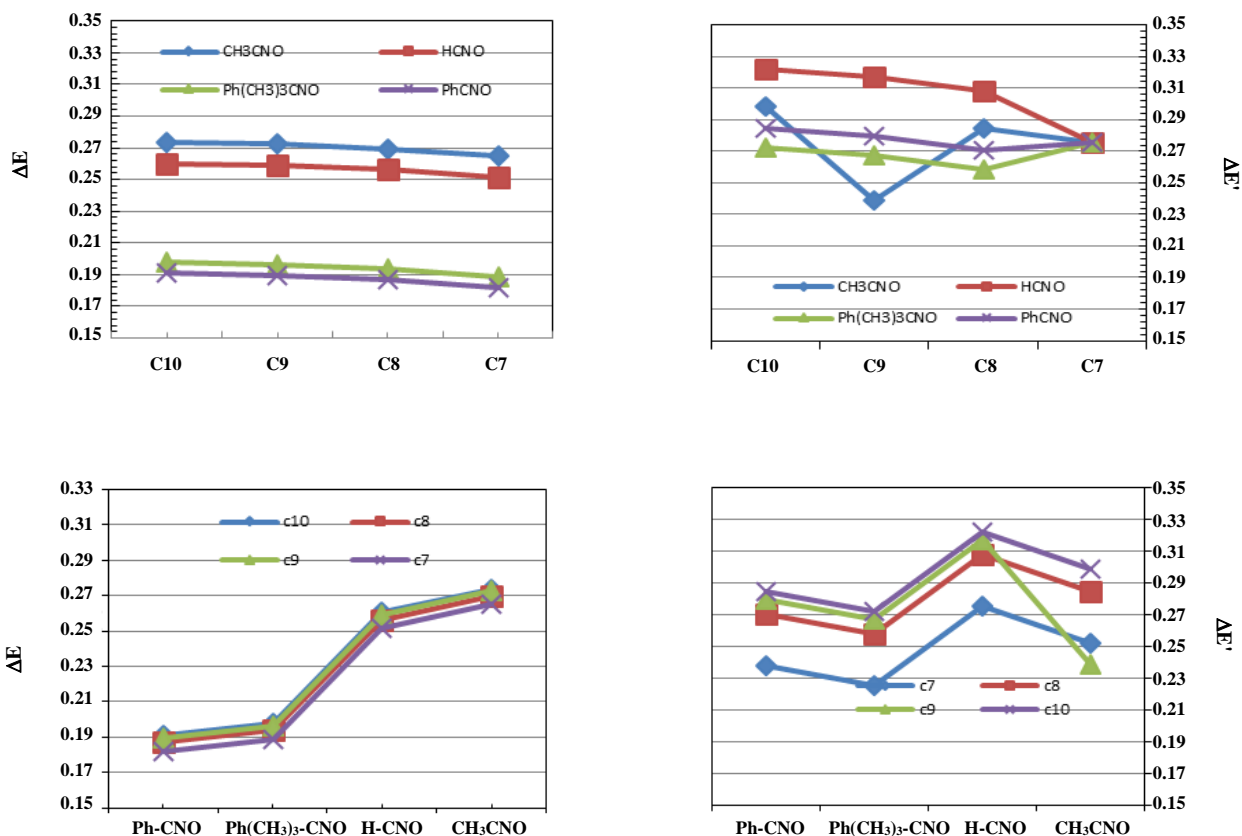


**Fig 5: The plot of  $\Delta G$ ,  $\Delta G^*$  versus: a,d) size of cycloalkynes and b,c) substituent groups (R).**

Table 5: The energies of HOMO & LUMO changes in hartree<sup>a</sup>.

Dipolarophile		C7		C8		C9		C10	
dipole	$\Delta E$	$\Delta E^I$	$\Delta E$	$\Delta E^I$	$\Delta E$	$\Delta E^I$	$\Delta E$	$\Delta E^I$	$\Delta E$
HCNO	0.2516	0.2758	0.2564	0.3083	0.2592	0.3175	0.2603	0.3225	
CH <sub>3</sub> CNO	0.2648	0.2522	0.2696	0.2846	0.2724	0.239	0.2735	0.2988	
Ph(CH <sub>3</sub> ) <sub>3</sub> -CNO	0.1889	0.2256	0.1937	0.2581	0.1965	0.2673	0.1976	0.2723	
PhCNO	0.1822	0.2379	0.187	0.2704	0.1898	0.2796	0.1909	0.2846	

$$^a \Delta E = E_{LUMO(dipole)} - E_{HOMO(dipolarophile)} \quad \Delta E^I = E_{LUMO(dipolarophile)} - E_{HOMO(dipole)}$$

Fig 6: The plot of  $\Delta E$ ,  $\Delta E^I$  (HOMO-LUMOgap) versus a,b) size of cycloalkynes (R) and c,d) substituent groups.

The kinetic stabilities were getting decrease by decreasing the ring sizes and increasing the strain energies of cycloalkynes. The bond angle strain release is an effective motive force of these reactions. Another one is reaching to the aromatic property of the nitrile oxides derivatives as the favored products of the reaction. Table 5 shows the energies of HOMO and LUMO for reactions. Also by comparing data of energies for HOMO and LUMO, it showed that electron-withdrawing groups for example phenyl group on dipole causing the smaller

HOMO-LUMO energy gap by lowering the LUMO. Against, electron-donating groups example methyl group on dipole causing the bigger HOMO-LUMO energy gap by raising the HOMO (see Table 5 and Fig 6).

## CONCLUSIONS

Comparing results shows that in the 1,3-dipolar cycloaddition reactions of C<sub>7</sub> to C<sub>10</sub> and R-CNO (R = H, CH<sub>3</sub>, Ph and Ph(CH<sub>3</sub>)<sub>3</sub>) for producing heterocycles, the free energies changes in reactions increases as the size of

the ring decreases. Also, the chemical affinity of cycloalkynes increases by increasing the bond angle strain around the triple bonds. The free energies ( $\Delta G^*$  and  $\Delta rG$ ) of the reactants, transition states, and products in the reactions of cycloalkynes with nitrile oxide derivatives are recorded by using B3LYP/6-31G\* calculations at 298 K. The kinetic data (rate constants =  $k$  in  $M^{-1} s^{-1}$  and relative constants =  $k'$ ) were calculated by Eyring equation, derived from transition state theory. In these exothermic reactions, the  $k$  and  $k'$  of the reactions increased by decreasing the size of the rings and increasing the strain energies and chemical affinity of cycloalkynes. Two factors, i.e., bond angle strain release and reaching to an aromatic property of the nitrile oxide derivatives as the favored products of the exothermic reactions are the main motive forces of these reactions. Also, the results showed that electron-withdrawing groups on dipole causing the smaller HOMO-LUMO energy gap by lowering the LUMO.

Received : Sept. 20, 2017 ; Accepted : Jul. 30, 2018

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