Electronic Supplementary Material (ESI) for Polymer Chemistry.

Electronic Supporting Information

On the Structure-Control Relationship of Amide-Functionalized SG1-Based Alkoxyamines for Nitroxide-Mediated Polymerization and Conjugation

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1. DFT Calculations

All calculations were performed with the Gaussian 03 molecular orbital package.[1] The geometry optimizations were carried out without constraints at the UB3LYP/6-31++G(d,p) level of theory. Vibrational frequencies were calculated at the UB3LYP/6-31++G(d,p) level to determine the nature of the located stationary points. Frequency calculations were performed to confirm that the geometry was a minimum (zero imaginary frequency). The single-point energies were then calculated at the UB3LYP/6-311++G(3df,3pd) level of theory.

2. Estimation of Charton constant υ, the electrical Hammet constants σ_I, and the radical stabilization constants σ_{RS}

The values reported in Table S1 were determined as reported in the literature. However, many of the alkyl moieties cannot be described by parameters given in the literature. For example, the effect of polar groups attached to the nitrogen atom of amide on the electrical Hammet constants σ_I is not reported. For the sake of simplicity, $\sigma_I = 0.07$, *i.e.* no influence of the long-range polar group, was chosen to **3**, **4**, and **6** to plot Figure 1.

In a similar manner, the steric Charton υ for $CONMe_2$ is not reported. However, based on the similitude approach, as $\upsilon_{CONH2} = \upsilon_{COOH}$, it was assumed $\upsilon_{CONMe2} = \upsilon_{COOMe} = 0.90$. For the steric Charton υ of monosubstitued *N*-alkyl amide moieties, it must be mentioned that amide group exhibit two diasteroisomers Z (H s-trans to the C=O) and E (H s-cis to the C=O), the isomer Z being favored due to relief of steric strain. Hence, since the steric hindrance is assumed to be only due to the group pointing to the nitroxide, the bulkiness of the amide group should be well-described by the value of $CONH_2$, that is: $\upsilon_{CONHR} = \upsilon_{CONH2} = 0.5$.

Alkoxyamine	E_a (kJ.mol^{-1})	σ_{RS}	σ_I	υ
BlocBuilder (1)	112	0.21	0.07	1.24
2	105.5	0.20	0.06	1.42
3a	122.0	0.20	0.07	1.25
3b	125.0	0.20		1.25
4	117.9	0.20	0.07	1.25
5	123.5	0.20	0.07	1.25
6	121.6	0.20	0.06	1.25
7	112.3	0.20	0.07	1.42
AMA (8)	130.7/132.8	0.18	0.09	0.83
9	124.5	0.18	0.09	1.01
10	135	0.18	0.09	1.01
AMA-NHS (11)	127.2	0.18	0.19	0.83
AMA-Gem (12)	131	0.18	0.06/0.13	1.01
13	115/116	0.34	0.05	1.06
14	124.5	0.18	0.11	1.03
15	123.4	0.18	0.09	1.2
16	130	0.18	0.09	1.03

The 7 kJ.mol^{-1} lower E_a for **2** compared to **7** is due to the presence of the phenyl group, which significantly increases the polarity. Interestingly, alkoxyamine **3–6** exhibit 5–12 kJ.mol^{-1} higher E_a than **7**. This difference is due to the occurrence of hydrogen-bonding between the hydrogen-atom of the secondary amide and the P=O moiety. The influence of this intramolecular hydrogen bonding (IHB) is slightly modified by the occurrence of a second weak hydrogen-bonding, between the hydrogen-atom of the secondary amide and the O-N moiety, the polarity (**4** and **6**) and the bulkiness (**5** and **6**) of the alkyl substituent. The same trend is observed for **9**, **10**, **12**, **15** and **16**.

It was not possible to estimate σ_I for alkoxyamine **12**. To have a first approximation, we used the σ_I that was used for alkoxyamine **2**, that is the polarity of an aromatic ring linked to the amide functionality. This value could be seen as a lower limit of σ_I. To estimate the polarity of the cytosine moiety, we used the polar parameter of the oxo-pyrimidinyl group[2] ($\sigma_{I,R1}$ = 0.41). With this value the polar parameter σ_I increases from 0.06 to 0.13.

Equation for Figure 1 is the following:

y-intercept = -13.90 (40)

RS = 14.85 (77)

I = 20.01 (145)

u = 6.68 (29)

N = 40

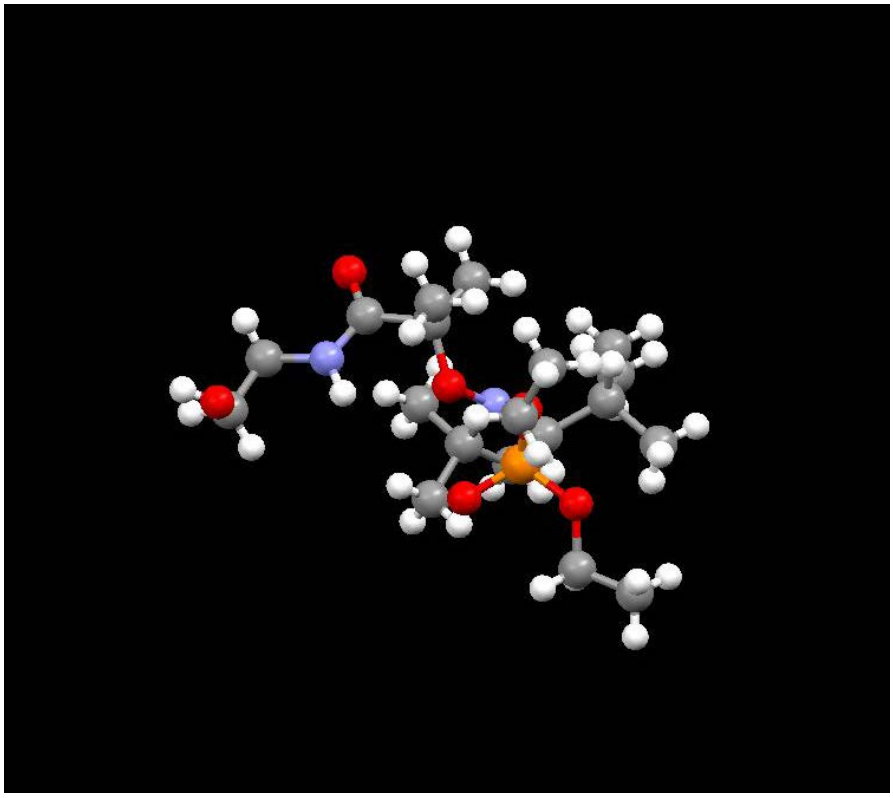
R^2 = 0.96

SD = 0.39

F = 287

$\forall$ t > 99.99%

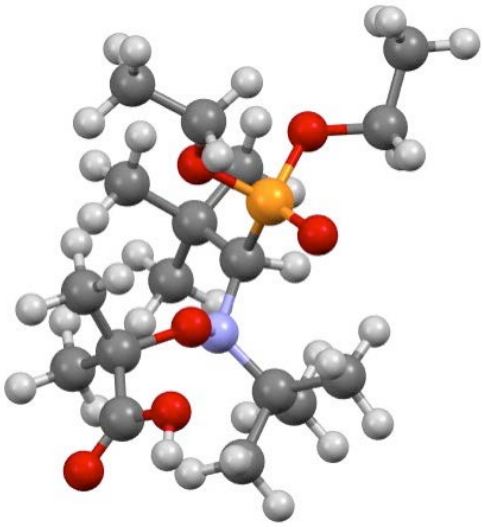
3. RX data for alkoxyamine 3b



4. DFT Calculations

Cartesian coordinates for alkoxyamines **1**, **17**, **18**, **19** and **20**.

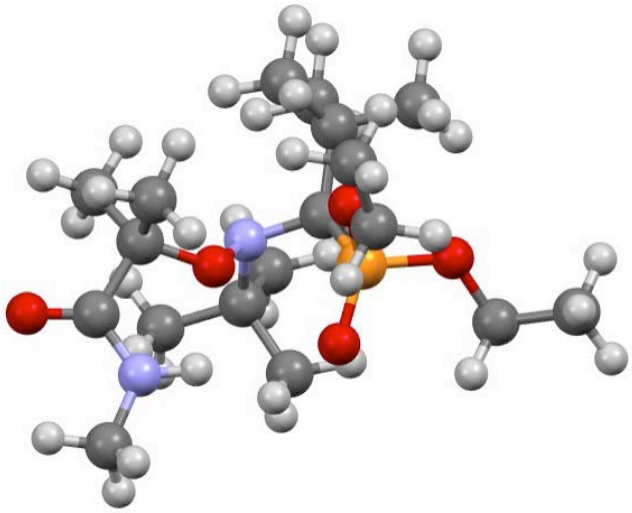
4.1 BlocBuilder 1



C	-5.22900	-0.35900	-1.28200
C	-3.76400	-0.75000	-1.38000
O	-3.02700	0.00200	-0.39100
P	-1.43700	0.34000	-0.61300
C	-0.54500	-0.98900	0.38800
C	-0.96100	-1.15500	1.92000
C	-0.01600	-2.17300	2.59500
O	-1.09800	0.43600	-2.05700
O	-1.33000	1.70800	0.24100
C	-1.85200	2.91700	-0.37000
C	-1.82400	4.02200	0.66900
N	0.92500	-1.02000	0.13700
C	1.39000	-2.03700	-0.89500
C	2.91000	-1.89000	-1.08100
O	1.31600	0.30800	-0.28300
C	2.37600	0.97400	0.46700
C	3.60800	1.12500	-0.45200
C	-2.38700	-1.74700	2.01000
C	-0.93600	0.14900	2.74300
C	1.13500	-3.44500	-0.32300
C	0.73000	-1.90800	-2.28000
C	1.85400	2.40000	0.72300
O	4.76100	0.99200	-0.10200
H	-3.63400	-1.82100	-1.17400
H	-3.35500	-0.53500	-2.37200
H	-1.23500	3.16000	-1.24100
H	-2.87600	2.72900	-0.71300
H	-0.95300	-1.88500	-0.09700
H	-5.62100	-0.55800	-0.28000
H	-5.81900	-0.93400	-2.00500
H	-5.35900	0.70600	-1.49900
H	-2.44800	3.76400	1.53000
H	-2.20800	4.95100	0.23100
H	-0.80500	4.20400	1.02100
H	-2.61700	-1.97900	3.05600
H	-2.46700	-2.68400	1.44400

H	-3.14700	-1.05800	1.63900
H	-1.69900	0.85500	2.41100
H	0.02900	0.65700	2.68700
H	-1.12600	-0.08800	3.79600
H	1.02800	-1.86400	2.54200
H	-0.09900	-3.16500	2.13900
H	-0.29700	-2.27500	3.65000
H	1.65300	-3.59100	0.62900
H	1.51500	-4.18600	-1.03600
H	0.07300	-3.66400	-0.17400
H	-0.33800	-2.14500	-2.26200
H	1.21000	-2.61200	-2.97000
H	0.83300	-0.89600	-2.67100
H	3.15400	-0.98700	-1.63900
H	3.28000	-2.74100	-1.66200
H	3.44300	-1.88600	-0.12600
H	1.51100	2.84500	-0.21500
H	1.01600	2.36600	1.42100
C	2.80400	0.30400	1.76900
H	1.97500	0.27100	2.47600
H	3.16700	-0.71100	1.61200
H	3.61700	0.88900	2.20500
H	2.64800	3.02800	1.14300
O	3.27300	1.50800	-1.70600
H	4.11700	1.61800	-2.18300

4.2 Alkoxyamine 17



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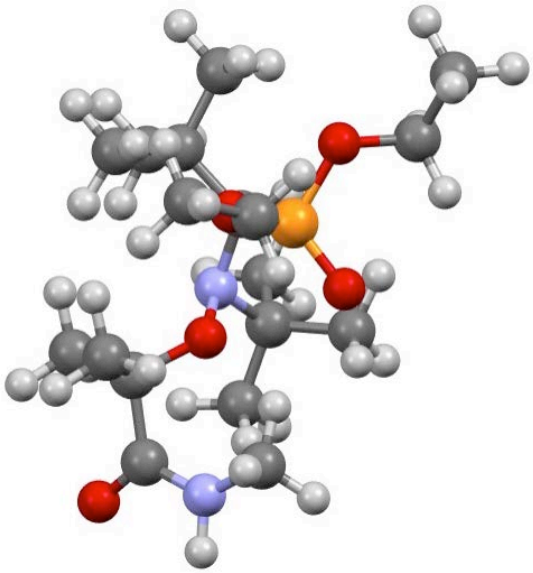
C	3.37200	0.06400	-2.17900
O	2.94800	-0.26300	-0.83600
P	1.36900	-0.53800	-0.49900
C	0.83400	1.07200	0.34100
C	1.42500	1.35700	1.78500
C	1.11600	2.82700	2.14200
O	0.63900	-1.02000	-1.70700
O	1.50200	-1.60500	0.70900
C	1.91700	-2.95900	0.39100

C	1.91200	-3.76600	1.67600
N	-0.63400	1.31900	0.23600
C	-1.03900	2.20000	-0.94400
C	-2.57100	2.29500	-1.00800
O	-1.21900	0.00300	0.08400
C	-2.33800	-0.44900	0.91300
C	-3.40500	-0.99800	-0.07800
N	-2.91100	-1.39400	-1.28200
C	-3.73700	-2.03500	-2.28800
C	2.96000	1.19300	1.79000
C	0.82800	0.47800	2.89600
C	-0.51500	3.62400	-0.67100
C	-0.52700	1.72800	-2.31900
C	-1.84500	-1.67100	1.71300
C	-2.96100	0.58300	1.84700
O	-4.57600	-1.13000	0.26700
H	3.24400	1.14400	-2.33300
H	2.73600	-0.46300	-2.89600
H	1.22500	-3.37300	-0.34900
H	2.91900	-2.92200	-0.05200
H	1.33300	1.80500	-0.30200
H	-3.81700	-1.41900	-3.19200
H	-4.73200	-2.17300	-1.86200
H	5.45200	0.18600	-1.58700
H	5.19100	-0.06600	-3.32600
H	4.95500	-1.40900	-2.18700
H	2.60300	-3.33700	2.40800
H	2.22400	-4.79600	1.46800
H	0.91100	-3.79100	2.11600
H	3.35100	1.54200	2.75300
H	3.43700	1.78800	1.00300
H	3.27000	0.15500	1.65900
H	1.02200	-0.58200	2.72900
H	-0.25000	0.63100	2.98300
H	1.27600	0.75900	3.85700
H	0.03900	3.01500	2.15300
H	1.58500	3.52600	1.44000
H	1.51000	3.05000	3.14100
H	-0.87200	4.00200	0.29100
H	-0.88700	4.29000	-1.45800
H	0.57700	3.69300	-0.68400
H	0.56500	1.75600	-2.39400
H	-0.91700	2.39800	-3.09300
H	-0.84500	0.71000	-2.54300
H	-3.03700	1.32400	-1.18000
H	-2.84900	2.94500	-1.84500
H	-2.98100	2.73800	-0.09700
H	-1.32400	-2.37000	1.05300
H	-2.70500	-2.18400	2.15600
H	-1.16300	-1.37000	2.50900
H	-2.21400	1.00200	2.52300
H	-3.73200	0.07800	2.43300
H	-3.44400	1.39700	1.30900
H	-1.92700	-1.22800	-1.46400
H	-3.32300	-3.01100	-2.56700

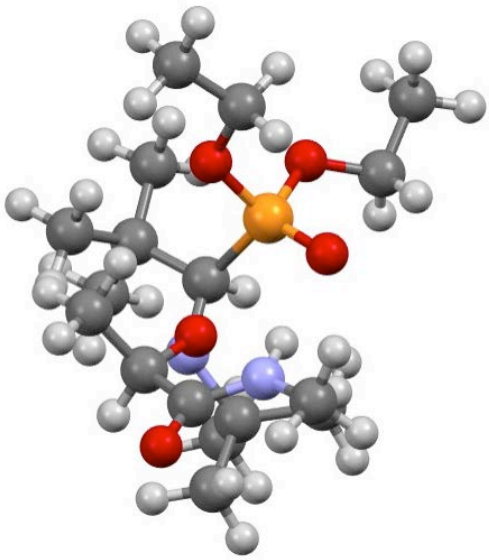
4.3 Alkoxyamine 18



C	-5.11600	-0.09300	-1.78000
C	-3.64800	-0.48000	-1.74400
O	-3.05500	0.10000	-0.56000
P	-1.45400	0.43700	-0.50500
C	-0.70100	-1.05500	0.37700
C	-1.17000	-1.33000	1.87500
C	-0.46800	-2.61000	2.37700
O	-0.93000	0.78900	-1.85400
O	-1.45400	1.63500	0.58000
C	-1.96700	2.93000	0.17100
C	-1.90300	3.86100	1.36700
N	0.76600	-1.18100	0.14800
C	1.16700	-2.10500	-0.99700
C	2.68300	-1.99600	-1.22700
O	1.26900	0.15200	-0.09200
C	2.37600	0.64600	0.73500
C	3.60800	0.93100	-0.17900
N	3.43800	1.54500	-1.39100
C	-2.69100	-1.60500	1.90300
C	-0.87500	-0.20200	2.88300
C	0.86800	-3.55000	-0.55100
C	0.46700	-1.83600	-2.34400
C	1.90700	1.99400	1.31400
C	2.81400	-0.28800	1.86100
O	4.73900	0.64700	0.20500
H	-3.53600	-1.57100	-1.69100
H	-3.11400	-0.11800	-2.62700
H	-1.36100	3.29900	-0.66200
H	-2.99800	2.80500	-0.17900
H	-1.16800	-1.86900	-0.19100
H	-5.63400	-0.44000	-0.88000
H	-5.60100	-0.54400	-2.65300
H	-5.22800	0.99400	-1.84600
H	-2.51300	3.48000	2.19200
H	-2.28300	4.85000	1.08600
H	-0.87300	3.97400	1.71900
H	-2.97400	-1.95000	2.90400
H	-2.97200	-2.39400	1.19300
H	-3.28400	-0.71900	1.67000
H	-1.41000	0.71600	2.64200

H	0.19000	0.03000	2.93900
H	-1.18900	-0.52900	3.88200
H	0.61900	-2.51100	2.34600
H	-0.74900	-3.48700	1.78600
H	-0.76900	-2.80300	3.41300
H	1.38300	-3.79400	0.38300
H	1.22100	-4.23900	-1.32700
H	-0.20100	-3.74200	-0.41600
H	-0.61200	-2.02100	-2.30400
H	0.87900	-2.51600	-3.09800
H	0.61300	-0.80800	-2.67600
H	2.95800	-1.02600	-1.64200
H	2.98200	-2.76300	-1.95000
H	3.25400	-2.16600	-0.31200
H	1.55300	2.66300	0.52500
H	2.73700	2.48400	1.83600
H	1.08700	1.84000	2.01700
H	1.99800	-0.46800	2.55900
H	3.64200	0.18500	2.39200
H	3.16900	-1.24800	1.48900
C	2.27300	2.14000	-2.03700
H	2.38600	2.03500	-3.12100
H	1.35700	1.63000	-1.74600
H	2.18500	3.21200	-1.81000
H	4.33800	1.73300	-1.81800

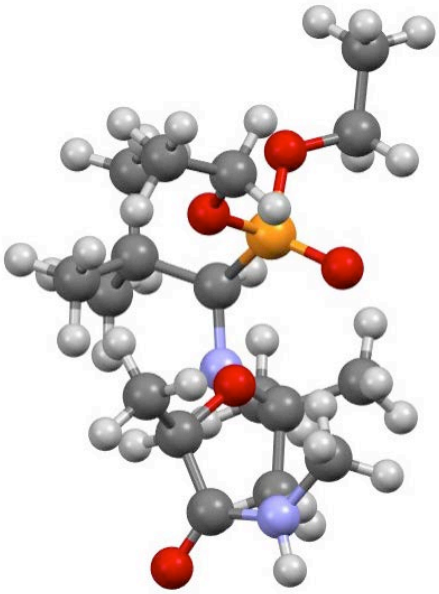
4.4 Alkoxyamine 19



C	4.56900	-0.61200	-2.49600
C	3.14400	-0.13600	-2.27600
O	2.77700	-0.42800	-0.90800
P	1.20500	-0.58400	-0.48300
C	0.81500	1.09100	0.30500
C	1.50300	1.40700	1.69600
C	1.38600	2.92400	1.95500
O	0.38400	-1.05400	-1.63800
O	1.32300	-1.60900	0.76000

C	1.61400	-3.00300	0.48200
C	1.58300	-3.75900	1.79700
N	-0.64600	1.38500	0.31900
C	-1.15500	2.23800	-0.83300
C	-2.68000	2.39600	-0.69300
O	-1.25000	0.06200	0.27700
C	-2.44900	-0.17200	1.03700
C	-3.46700	-0.86800	0.10900
N	-2.94200	-1.39700	-1.02700
C	-3.74400	-2.15500	-1.96900
C	3.00600	1.05800	1.68100
C	0.82100	0.68600	2.86900
C	-0.54800	3.64700	-0.67900
C	-0.84000	1.69900	-2.24000
C	-2.19900	-1.08300	2.24200
O	-4.64300	-0.96500	0.45100
H	3.06900	0.94900	-2.43400
H	2.44100	-0.63100	-2.95100
H	0.86600	-3.38300	-0.22000
H	2.60000	-3.06600	0.01000
H	1.28900	1.76800	-0.41500
H	-3.78800	-1.65800	-2.94600
H	-4.75300	-2.23200	-1.56200
H	5.25700	-0.12500	-1.79700
H	4.88900	-0.37700	-3.51800
H	4.64100	-1.69500	-2.35200
H	2.32900	-3.36300	2.49300
H	1.80000	-4.81900	1.62100
H	0.59700	-3.68300	2.26600
H	3.46200	1.41600	2.61200
H	3.53000	1.53900	0.84700
H	3.18400	-0.01700	1.61400
H	0.84300	-0.39900	2.75100
H	-0.21700	1.01300	2.96400
H	1.33700	0.94100	3.80300
H	0.34100	3.24100	1.99600
H	1.90000	3.51300	1.18500
H	1.84900	3.16700	2.91800
H	-0.80900	4.09000	0.28600
H	-0.95500	4.28800	-1.46800
H	0.54000	3.66200	-0.78300
H	0.23500	1.67100	-2.44500
H	-1.29500	2.36100	-2.98600
H	-1.22900	0.69200	-2.38300
H	-3.21600	1.46800	-0.90300
H	-3.02800	3.14100	-1.41600
H	-2.95200	2.74900	0.30700
H	-1.66400	-1.98500	1.92600
H	-3.16400	-1.37600	2.66600
H	-1.61100	-0.58100	3.01100
H	-1.95200	-1.25500	-1.20700
H	-3.33300	-3.16200	-2.11000
H	-2.87800	0.77600	1.36200

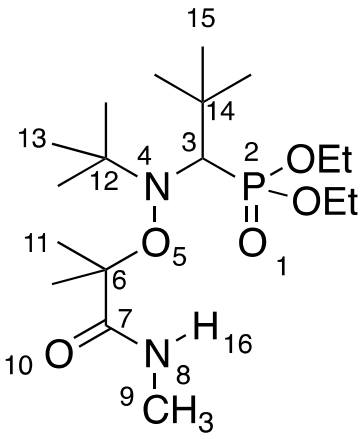
4.5 Alkoxyamine 20



C	0.00000	0.00000	0.00000
C	0.00000	0.00000	1.51900
O	1.37300	0.00000	1.96900
P	1.75300	-0.53200	3.47100
C	1.93600	1.05800	4.46500
C	3.15500	2.00600	4.09700
C	2.92000	3.37400	4.77200
O	0.78400	-1.55800	3.94400
O	3.26900	-1.04000	3.22500
C	3.46700	-2.27200	2.48300
C	4.96000	-2.49600	2.33200
N	1.79500	0.85200	5.93100
C	0.42200	1.11000	6.52000
C	0.48900	0.80700	8.02700
O	2.17600	-0.52300	6.20000
C	3.24200	-0.67000	7.16100
C	2.79500	-1.32000	8.48500
N	1.97900	-2.41700	8.45900
C	3.23500	2.25000	2.57600
C	4.51300	1.47900	4.59000
C	0.10300	2.61100	6.37200
C	-0.71300	0.28100	5.89200
C	4.37100	-1.51500	6.55900
O	3.22600	-0.87500	9.54500
H	-0.49800	0.90000	1.90600
H	-0.51300	-0.87700	1.92400
H	2.98800	-3.09000	3.03000
H	2.98100	-2.17500	1.50600
H	1.04600	1.60300	4.12500
H	0.53400	0.87200	-0.39100
H	-1.03000	0.02800	-0.37400
H	0.48400	-0.90300	-0.38600
H	5.42500	-1.66700	1.78900
H	5.14200	-3.42100	1.77500
H	5.44300	-2.58300	3.31100
H	3.99800	3.01300	2.37800
H	2.28500	2.61900	2.17100
H	3.50800	1.35100	2.02100
H	4.77800	0.53400	4.11400

H	4.51600	1.34900	5.67500
H	5.29300	2.21100	4.34600
H	2.86800	3.27600	5.85900
H	1.99900	3.85300	4.42000
H	3.75200	4.04600	4.53200
H	0.84800	3.23200	6.87500
H	-0.87000	2.80400	6.83700
H	0.02800	2.93600	5.33000
H	-0.91100	0.56400	4.85300
H	-1.63800	0.45100	6.45600
H	-0.48100	-0.78400	5.90300
H	0.52000	-0.26600	8.22100
H	-0.40900	1.20300	8.51300
H	1.36100	1.27500	8.49300
H	4.01100	-2.51000	6.27800
H	5.16900	-1.63600	7.30000
H	4.78000	-1.03600	5.66900
C	1.49400	-3.20900	7.33500
H	0.47600	-3.55000	7.55000
H	1.46000	-2.61000	6.42600
H	2.12100	-4.09600	7.16200
H	1.83400	-2.79600	9.38800
H	3.60300	0.32300	7.43300

5. Bond length, distance between atoms and valence angle determined for alkoxyamines 1, 3b, 17, 18, 19 and 20



	17	**18**	**1**	**19**	**20**	**3b (X-ray)**
l (Å)						
N4—O5	1.448	1.445	1.447	1.455	1.452	1.460
C3—P2	1.893	1.890	1.888	1.892	1.884	1.842
P2—O1	1.491	1.489	1.486	1.493	1.488	1.460
O5—C6	1.464	1.467	1.459	1.439	1.443	1.471

N8—H16	1.014	1.014	-	1.016	1.014	0.977
d (Å)						
N4···C6	2.547	2.505	2.488	2.488	2.434	2.503
O1···C7	4.360	4.839	5.020	4.233	4.972	4.992
O1···H16	2.586	5.352	-	2.384	5.681	2.373
O5···H16	2.101	3.860	-	2.105	3.930	2.373
α (°)						
<N4O5C6>	122.0	118.7	117.8	118.6	114.4	117.3
<C11,HC6C7>	107.7	108.5	109.1	108.2	105.4	109.2
<C7C6O5>	105.8	109.9	108.5	107.8	113.6	109.0
<C11,HC6O5>	116.8	115.2	116.2	110.1	108.5	114.9
<C6C7N8>	114.7	120.2	-	115.1	119.7	117.3
<C7N8H16>	117.6	110.2	-	118.0	111.6	118.0
<O5H16N8>	106.7	-	-	106.7	-	102.9
<O1H16N8>	173.0	-	-	176.8	-	154.5
<C3N4O5>	104.7	106.9	107.1	103.1	109.1	106.5
θ (°)						
<O10C7C6$\sigma^*_{O5—C6}$> <O5C6C7O10> + 180° $n_{p,O10}\rightarrow\sigma^*_{O5—C6}$	18.9	39.2	38.6	12.6	41.2	55.5
<O5C6C7O10>	-161.1	-140.8	-141.4	-167.4	-138.8	-145.5
<π_{C7}C7C6O5> <O5C6C7O10> + 90° $\pi_{C7}\rightarrow\sigma^*_{O5—C6}$	-71.1	-50.8	-51.4	-77.4	-48.8	-55.5
<N4O5C6H,Me>	6.3	-4.7	-10.2	13.8	-4.6	-11.2
<C6O5N4$n_{\sigma,N4}$>	12.9	11.3	10.7	26.8	10.1	10.3
<C7C6O5N4>	129.6	117.6	113.5	131.6	112.3	111.7

<C7C6O5$n_{p,O5}$> <C7C6O5N4> - 90° $n_{p,O5}\rightarrow\sigma^*_{C6—C7}$	39.6	27.6	23.5	41.6	22.3	21.7
<O10C7N8H16>	179.5	*171.5*	-	179.9	171.3	177.2
<C15C14C3N4>	-175.4	-162.5	-154.1	-178.3	-177.5	-155.1
<C13C12N4O5>	174.4	168.3	172.2	176.5	173.5	179.1
<HC3N4O5>	135.2	136.5	134.2	134.7	135.7	134.0
<O1P2C3N4>	32.2	37.3	46.6	35.7	35.4	46.1

References

1 M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. A. Montgomery Jr., J. E. Peralta, F. Ogliaro, M. J. Bearpark, J. Heyd, E. N. Brothers, K. N. Kudin, V. N. Staroverov, R. Kobayashi, J. Normand, K. Raghavachari, A. P. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, N. J. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, Ö. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski and D. J. Fox, Gaussian, Inc., Wallingford, CT, USA, 2009.

2 C. Hansch, A. Leo and R. W. Taft, *Chem. Rev.* 1991, **91**, 165.