Supporting Information:

Feasibility of chitosan application for wastewater purification from diclofenac

Anna Kaczmarek-Kędziera*

Faculty of Chemistry, Nicolaus Copernicus University in Toruń, Gagarina 7, 87–100 Toruń, Poland

E-mail: teoadk@chem.umk.pl

Table S1: Basis set dependence of interaction energy for CS1:DFNa complexes in B97-D3 functional. P(d,p) denotes 6-31G(d,p) Pople basis set, P++(d,p) stands for Pople 6-311++G(d,p) basis set, P++(2df,2pd) is 6-311++G(2df,2pd) basis set. #bf is a number of basis functions for the corresponding basis set.

Basis set #bf	P(d,p) 657	P++(d,p) 961	P++(2df,2pd) 1585
B97-D3			
1	-37.14	-36.10	-35.43
2	-26.58	-25.54	-25.02
3	-24.84	-23.94	-23.84
4	-40.43	-38.46	-38.12
5	-34.78	-33.23	-32.88
6	-36.44	-34.84	-34.28
7	-24.64	-24.45	-23.86
7a	-33.70	-32.29	-31.79
8	-22.76	-21.79	-21.64
9	-35.68	-34.19	-33.57
10	-9.51	-9.74	-9.82

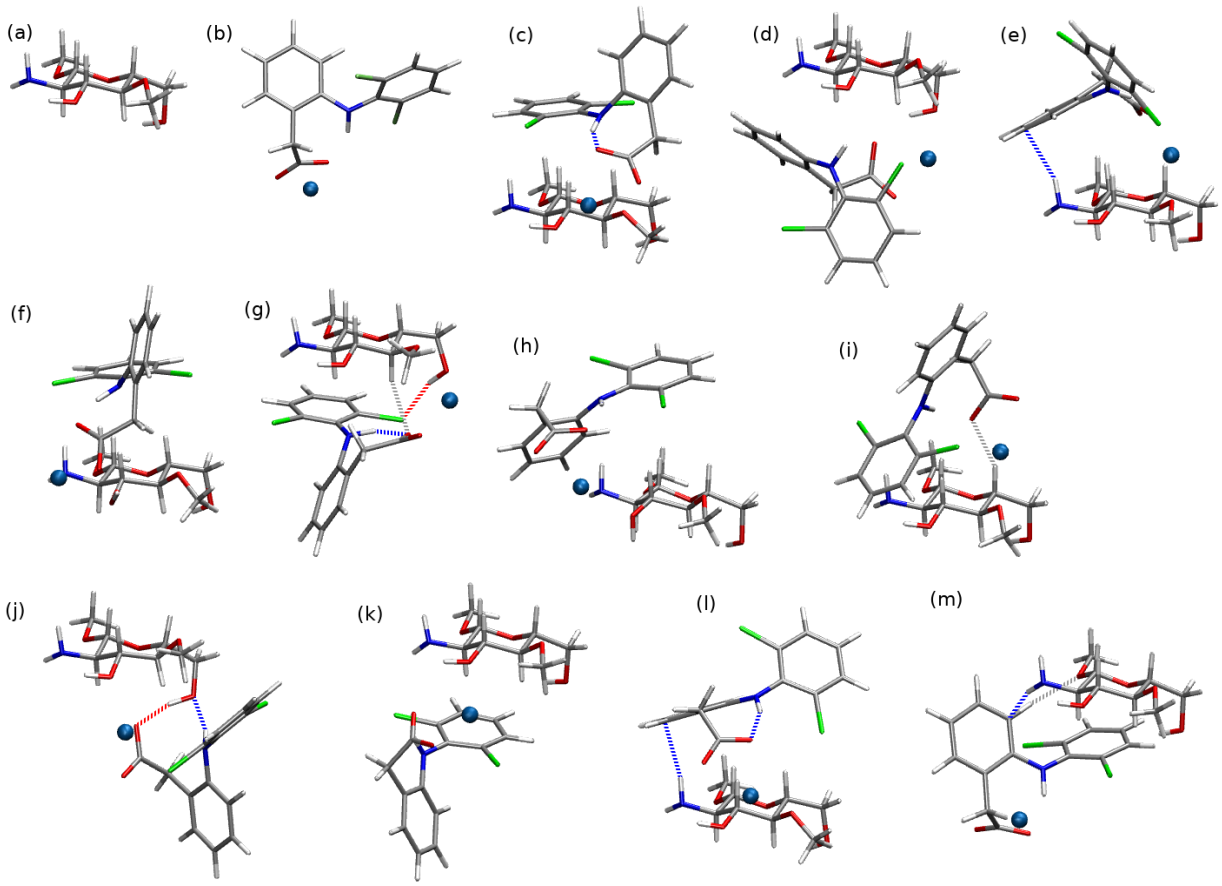

Figure S1: Optimized geometries for diclofenac sodium DFNa interacting with pristine chitosan unit CS1: (a) optimized chitosan unit CS1 – lowest energy conformation, (b) optimized diclofenac sodium molecule DFNa and CS1:DFNa complexes: (c) **1**, (d) **2**, (e) **3**, (f) **4**, (g) **5**, (h) **6**, (i) **7**, (j) **7a**, (k) **8**, (l) **9**, (m) **10** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

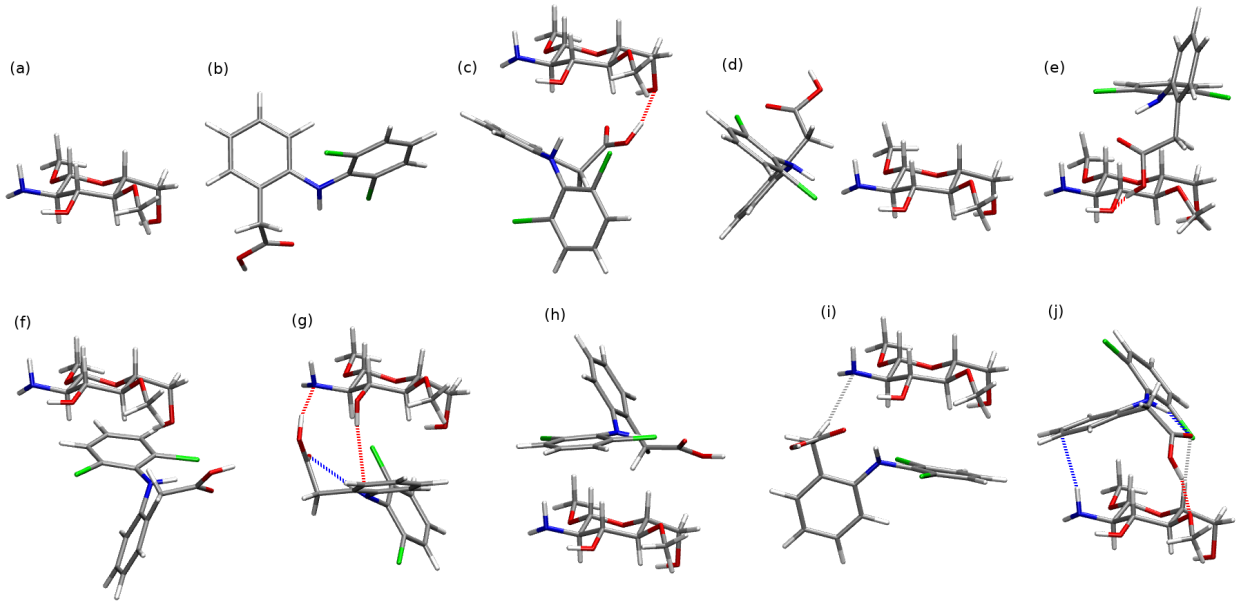

Figure S2: Optimized geometries for diclofenac (acidic form) DFH interacting with pristine chitosan unit CS1: (a) optimized chitosan unit CS1 – lowest energy conformation, (b) optimized diclofenac molecule DFH and CS1:DFH complexes: (c) **2**, (d) **3**, (e) **4**, (f) **5**, (g) **6**, (h) **7**, (i) **8**, (j) **9** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

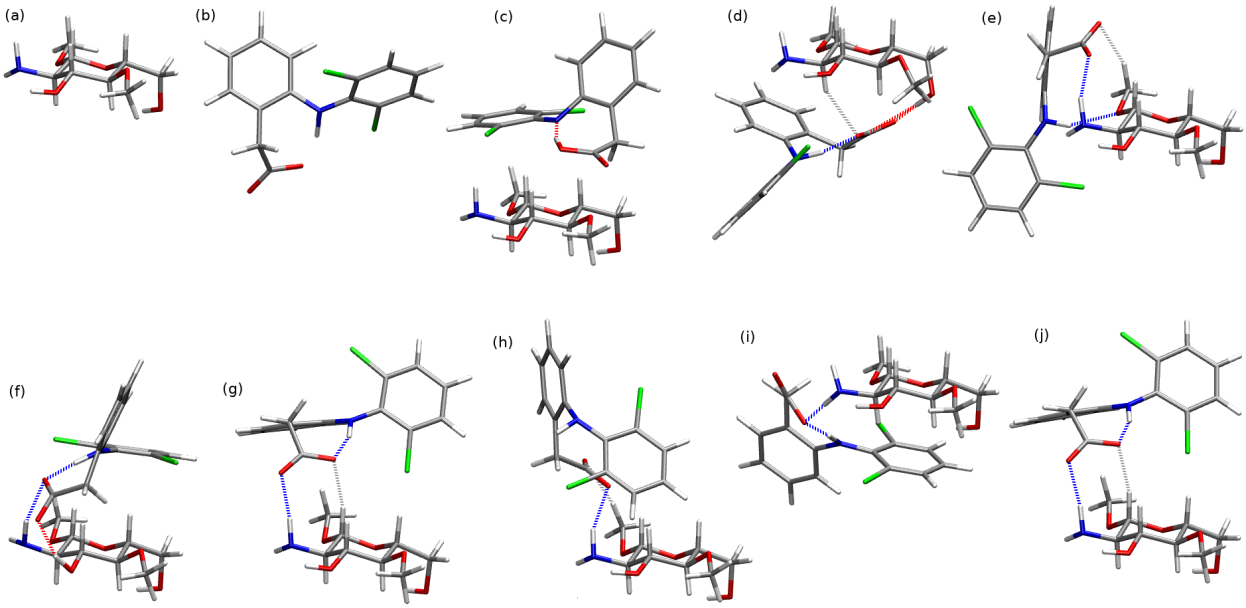

Figure S3: Optimized geometries for diclofenac anion DF^- interacting with pristine chitosan unit CS1: (a) optimized chitosan unit CS1 – lowest energy conformation, (b) optimized diclofenac anion DF^- and CS1:DF^- complexes: (c) **1-PT**, (d) **2**, (e) **3**, (f) **4**, (g) **6**, (h) **7a**, (i) **8**, (j) **9** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

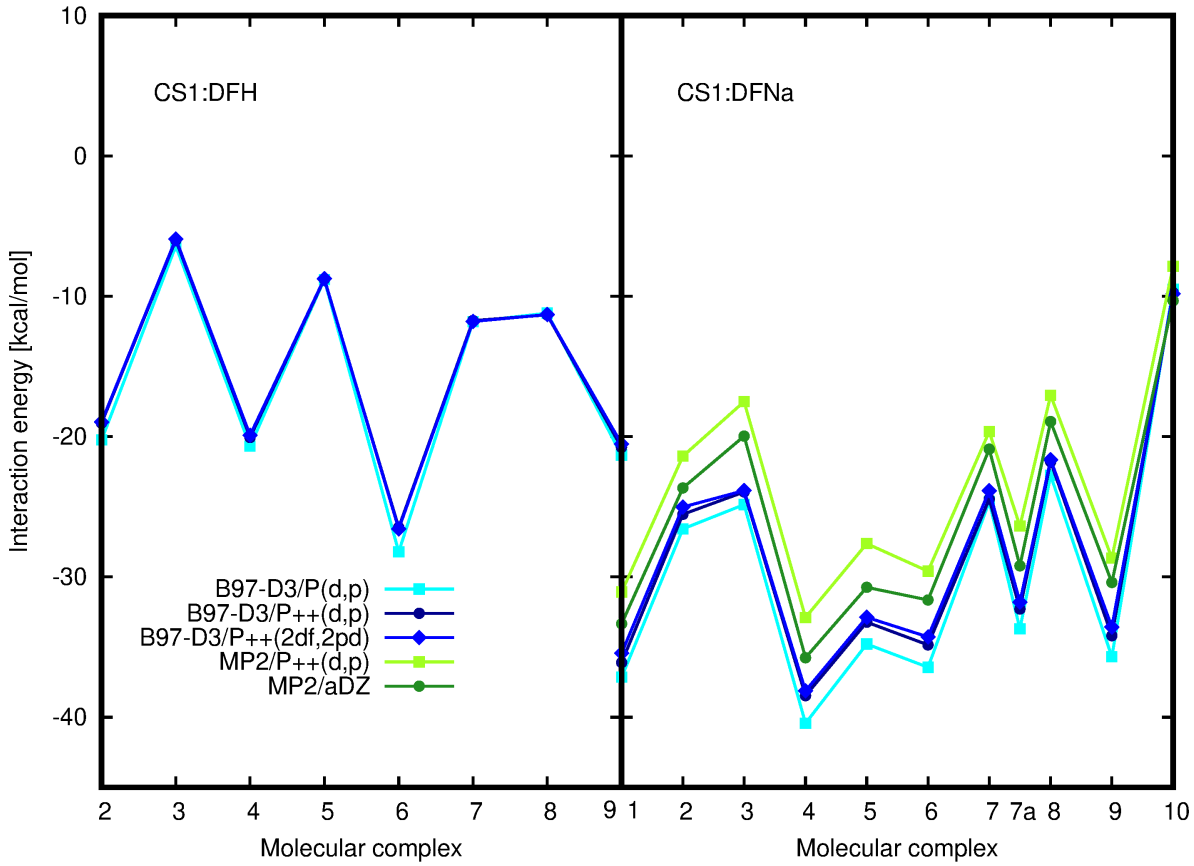

Figure S4: Basis set dependence of B97-D3 and MP2 supermolecular interaction energy for CS1:DFH and CS1:DFNa complexes

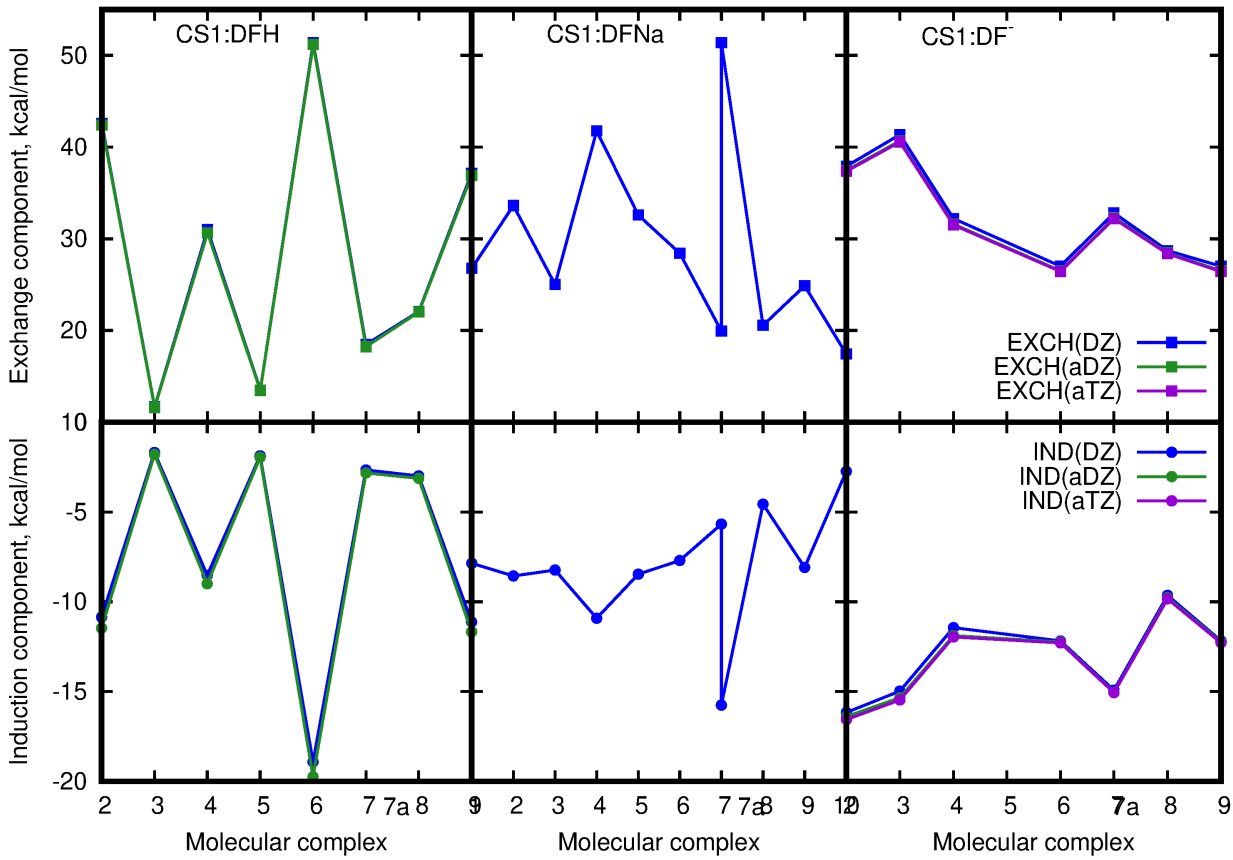

Figure S5: Induction and exchange SAPT0 interaction energy components for CS1:drug complexes

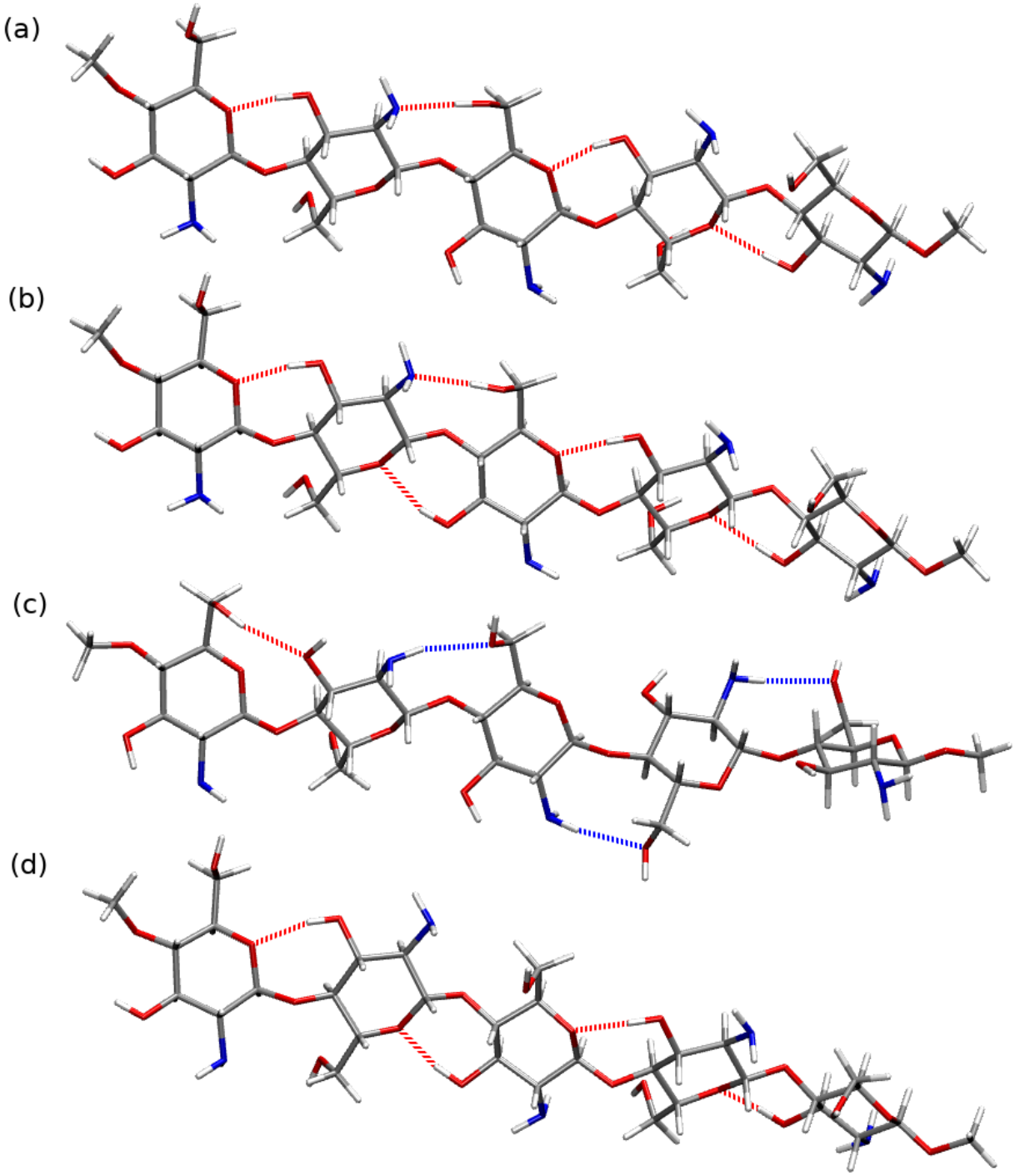

Figure S6: Optimized geometries for exemplary chitosan five-unit chains from different initial points. Relative B3LYP/6-31G(d,p) energy: (a) 0.00 kcal/mol, (b) 1.01 kcal/mol, (c) 8.96 kcal/mol and (d) 9.19 kcal/mol.

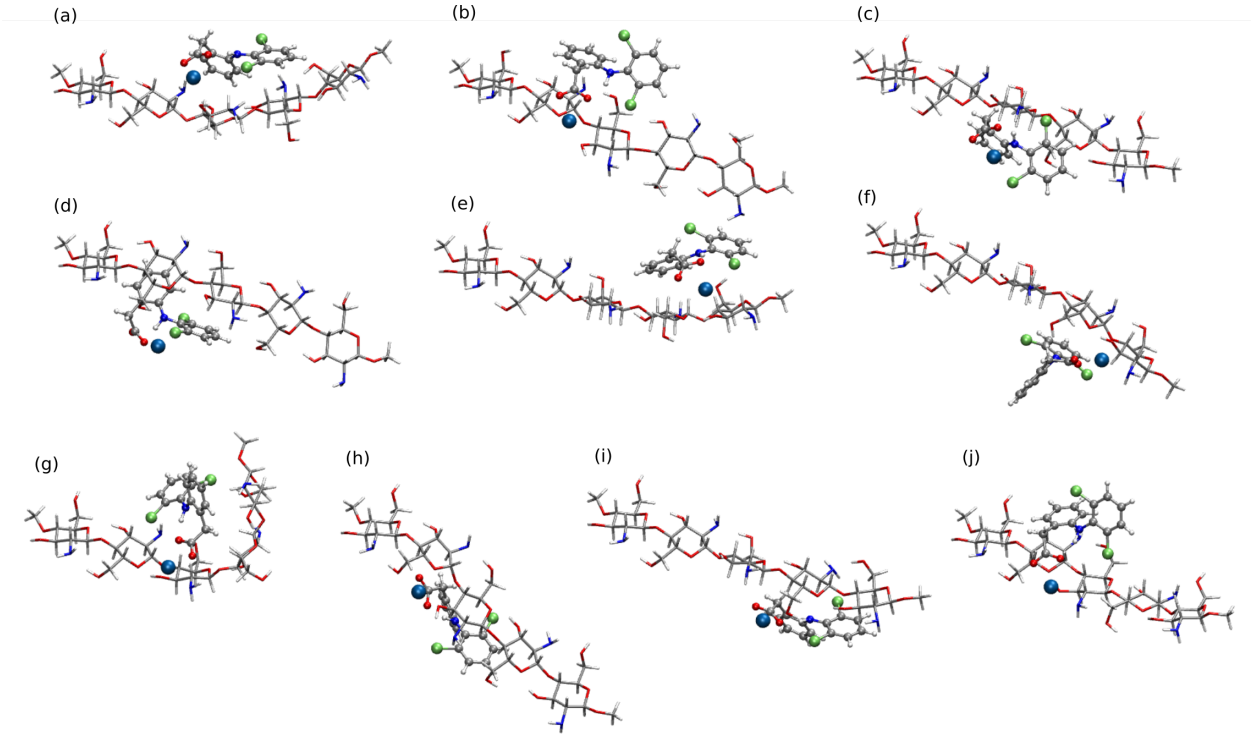

Figure S7: Optimized geometries for diclofenac sodium DFNa interacting with pristine chitosan unit CS5. CS5:DFNa complexes: (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

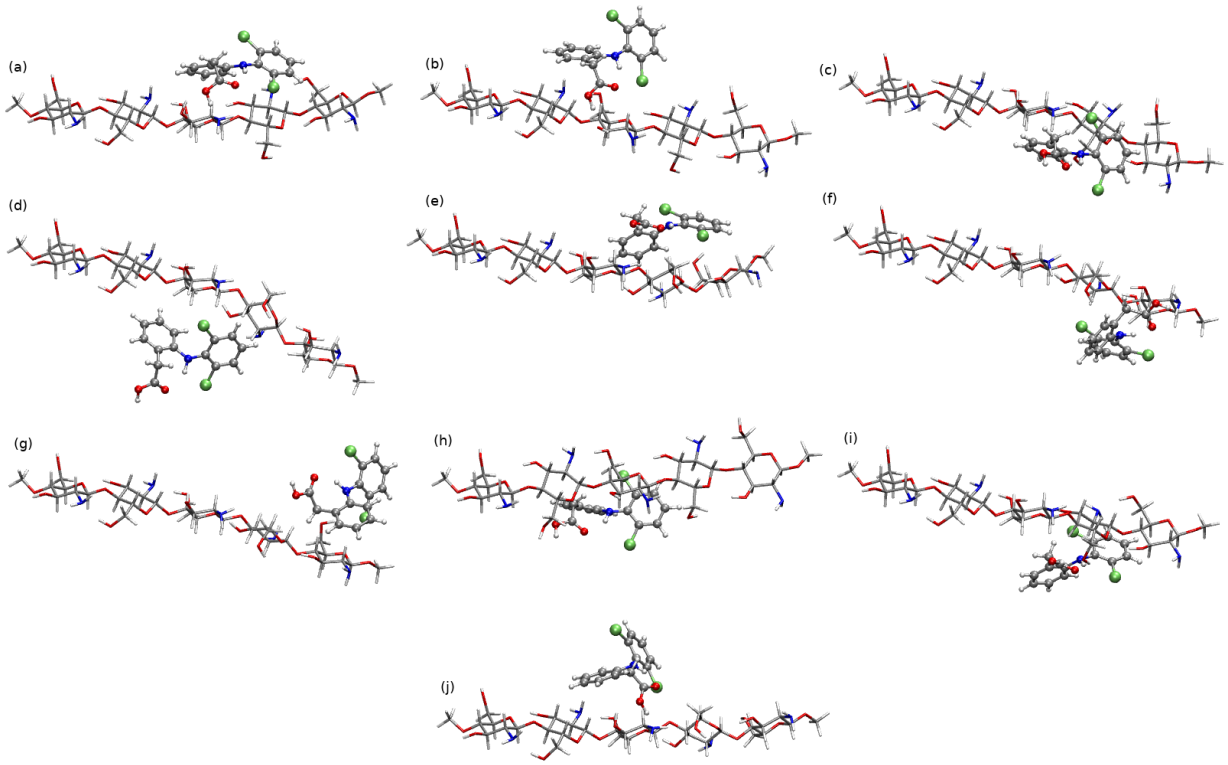

Figure S8: Optimized geometries for diclofenac DFH interacting with pristine chitosan unit CS5. CS5:DFH complexes: (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

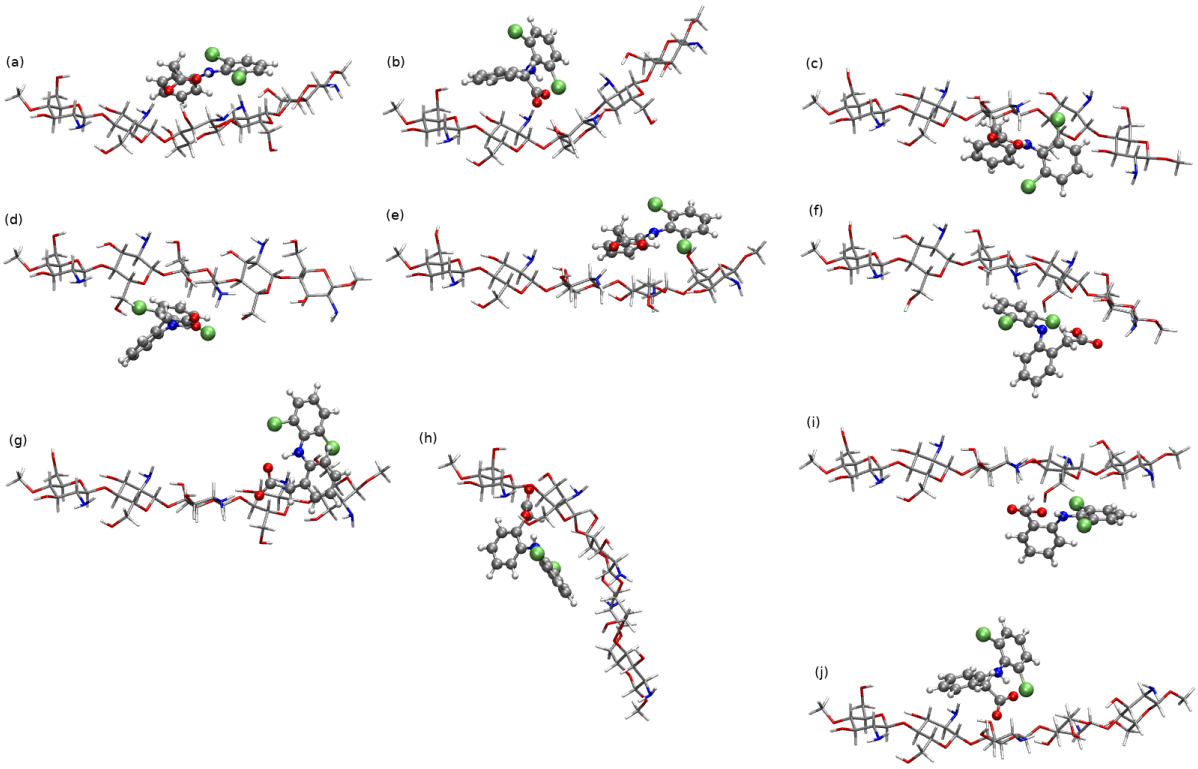

Figure S9: Optimized geometries for diclofenac anion interacting with pristine chitosan unit CS5. CS5:DF$^-$ complexes: (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10** (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

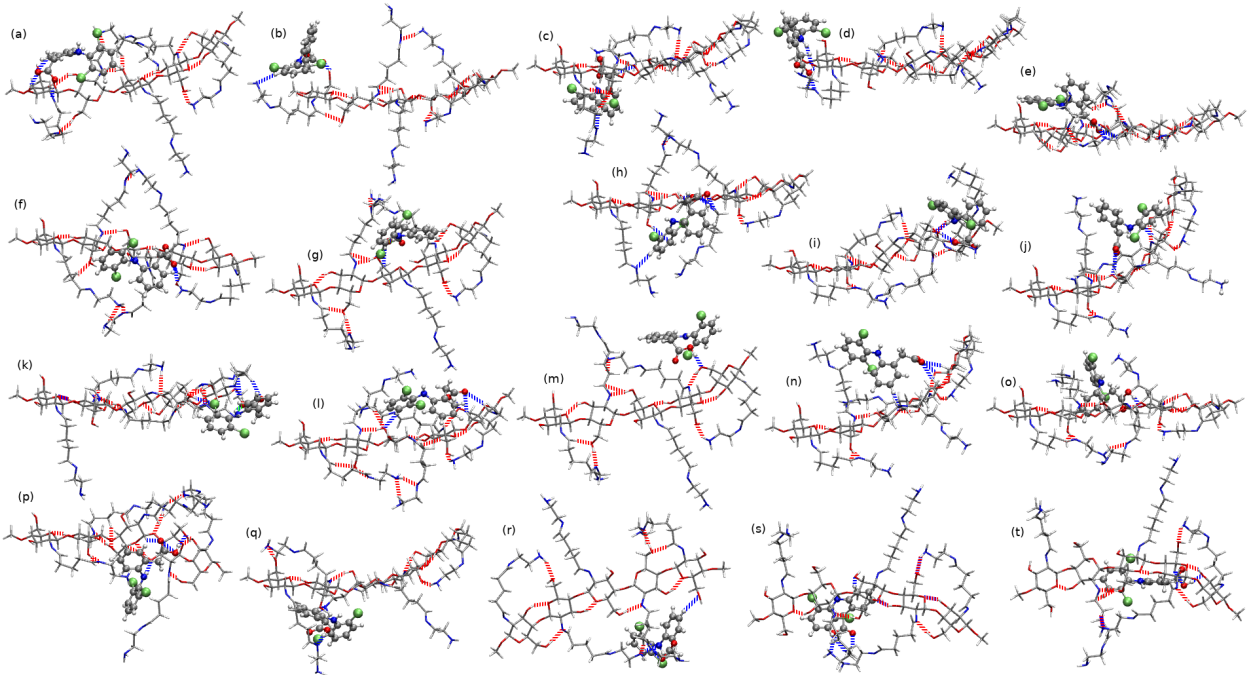

Figure S10: Optimized geometries for diclofenac acid DFH interacting with substituted chitosan unit CS5(NH_2). (carbon atoms – grey, hydrogen – white, nitrogen – blue, oxygen – red, chlorine – green; sodium cation presented as blue balls and H-bonds – dashed).

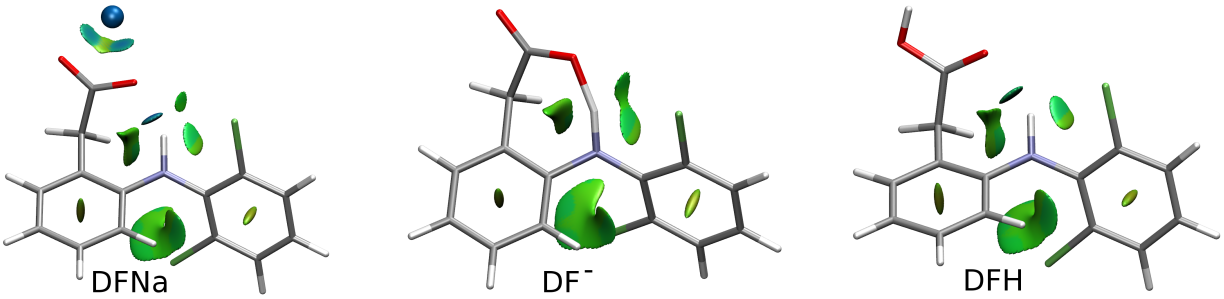

Figure S11: NCIPlot-calculated density »» for three investigated forms of diclofenac: DFNa, DF^- and DFH

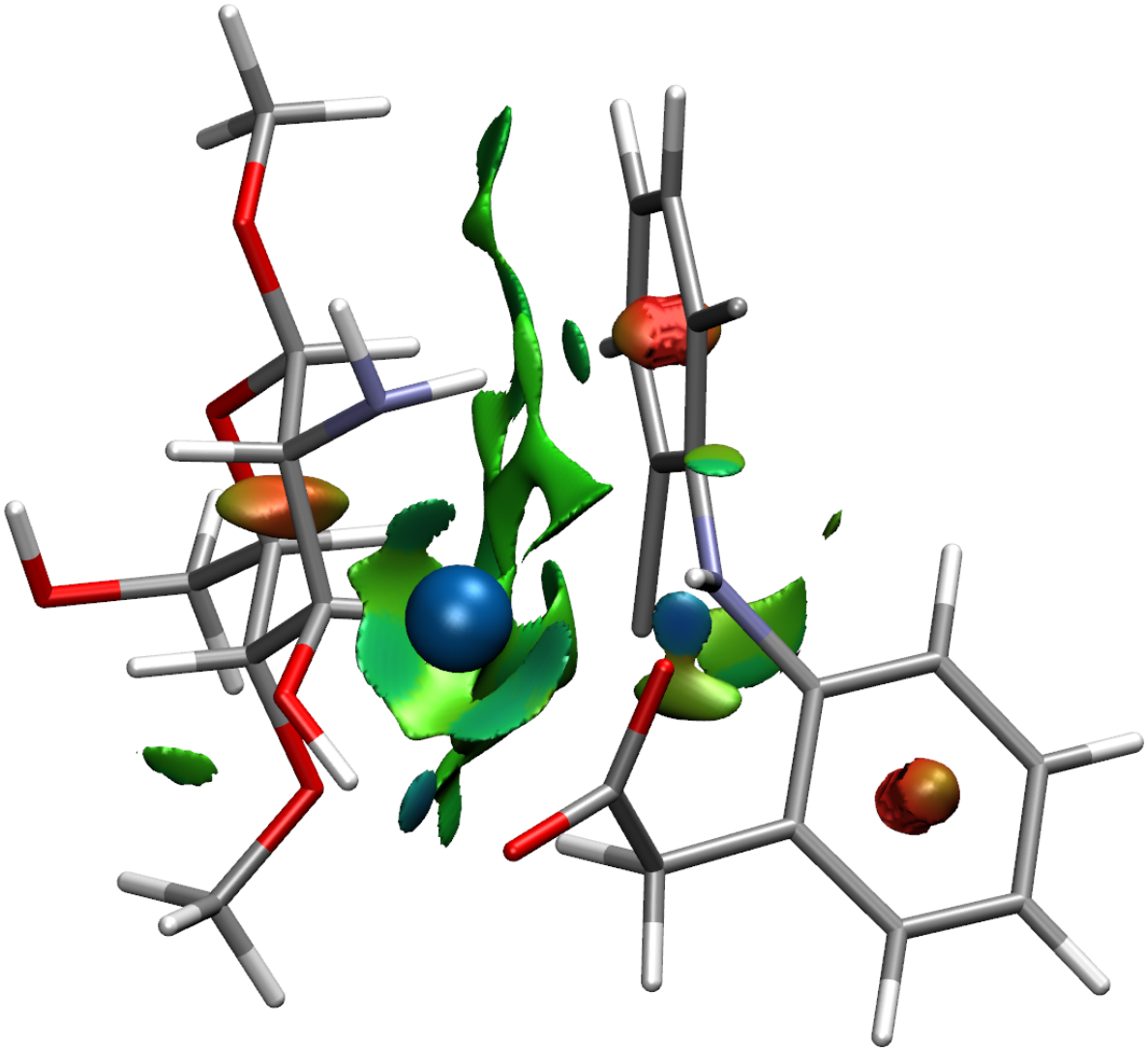

Figure S12: NCIPlot-calculated density »» for most stable structure **4**

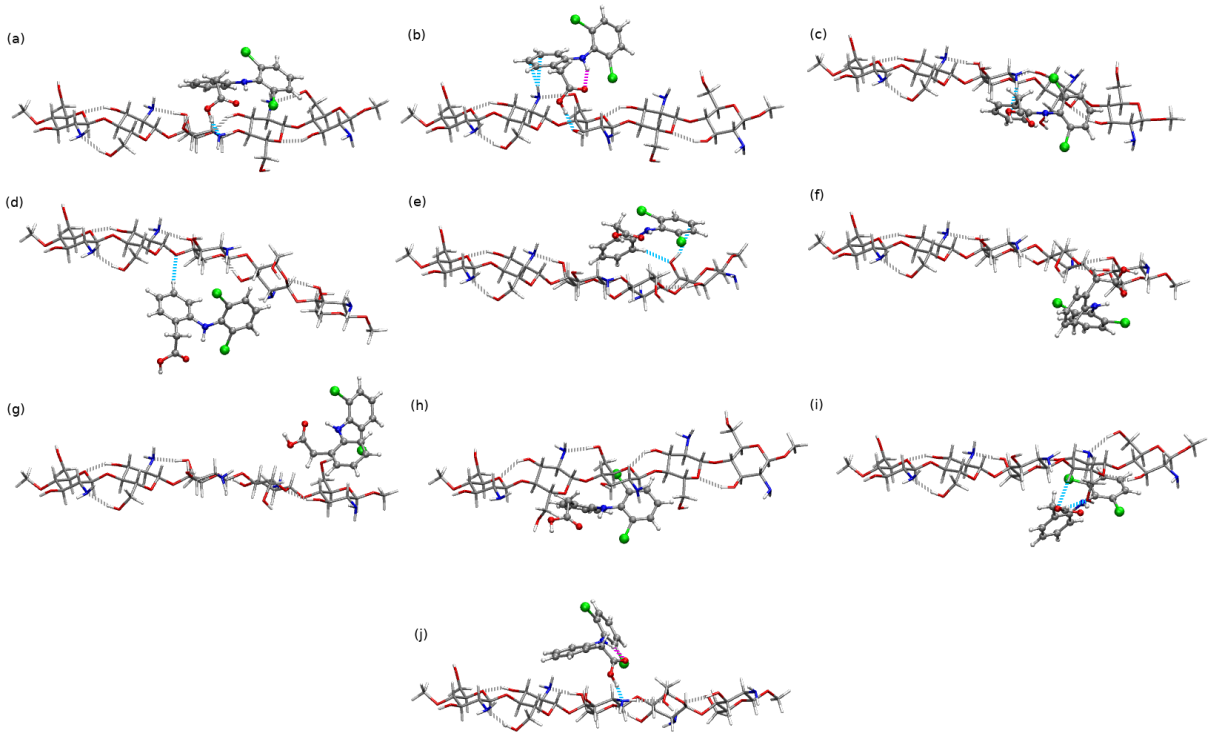

Figure S13: Optimized structures of CS5:DFH complexes (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10**. Dashed lines depict hydrogen bonds (cyan: intermolecular, magenta: intramolecular in DFH, grey: intramolecular in CS5). CS5 presented in licorice representation and DFH with balls.

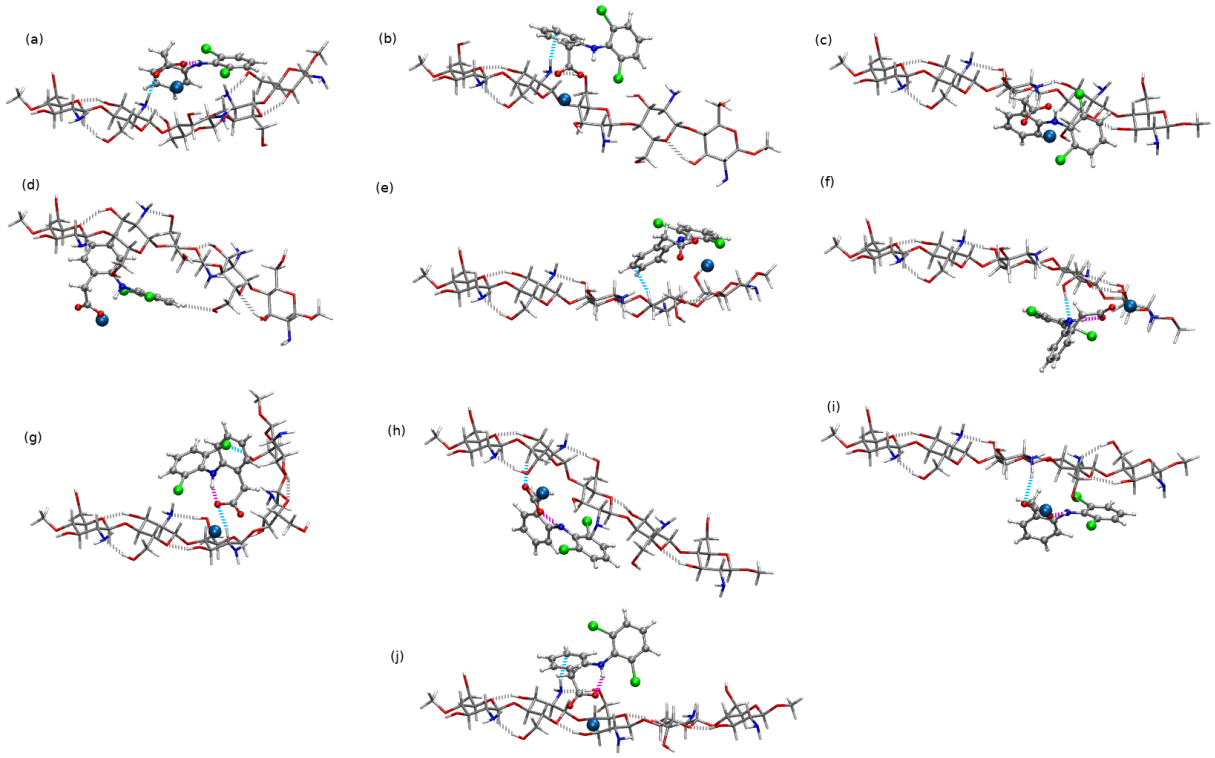

Figure S14: Optimized structures of CS5:DFNa complexes (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10**. Dashed lines depict hydrogen bonds (cyan: intermolecular, magenta: intramolecular in DFNa, grey: intramolecular in CS5). CS5 presented in licorice representation and DFNa with balls.

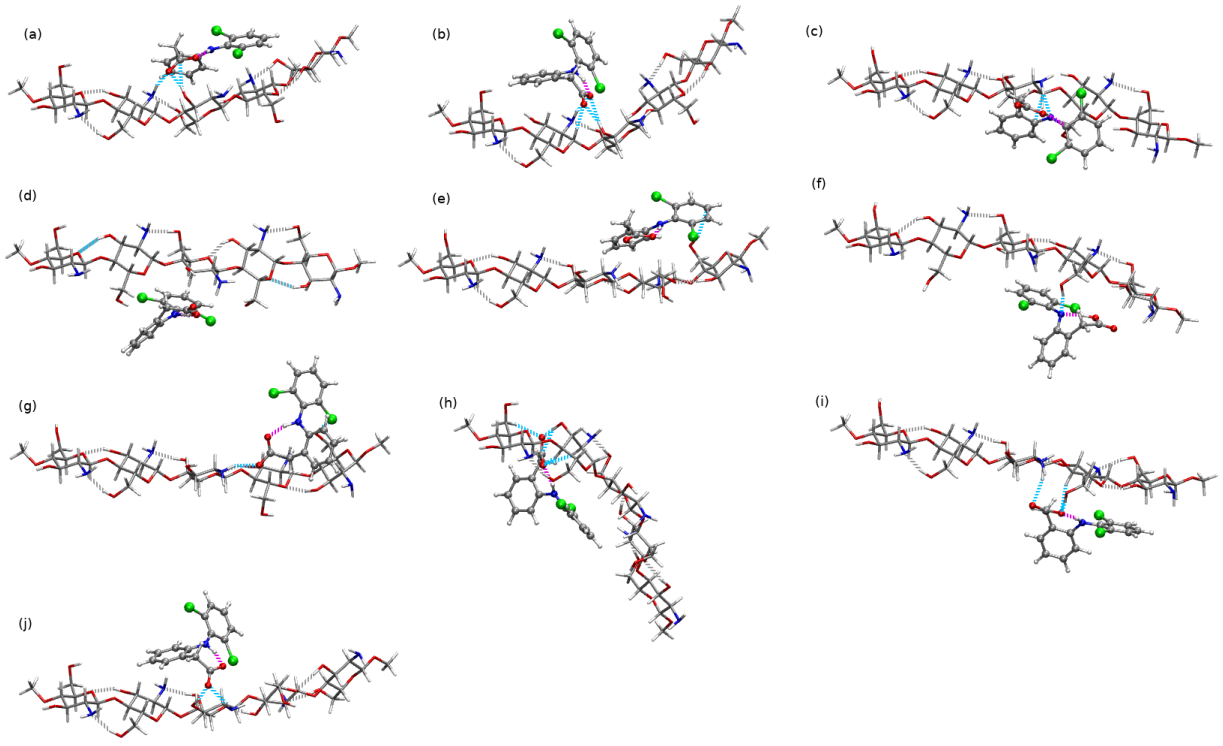

Figure S15: Optimized structures of CS5:DF^- complexes (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10**. Dashed lines depict hydrogen bonds (cyan: intermolecular, magenta: intramolecular in DF^-, grey: intramolecular in CS5). CS5 presented in licorice representation and DF^- with balls.

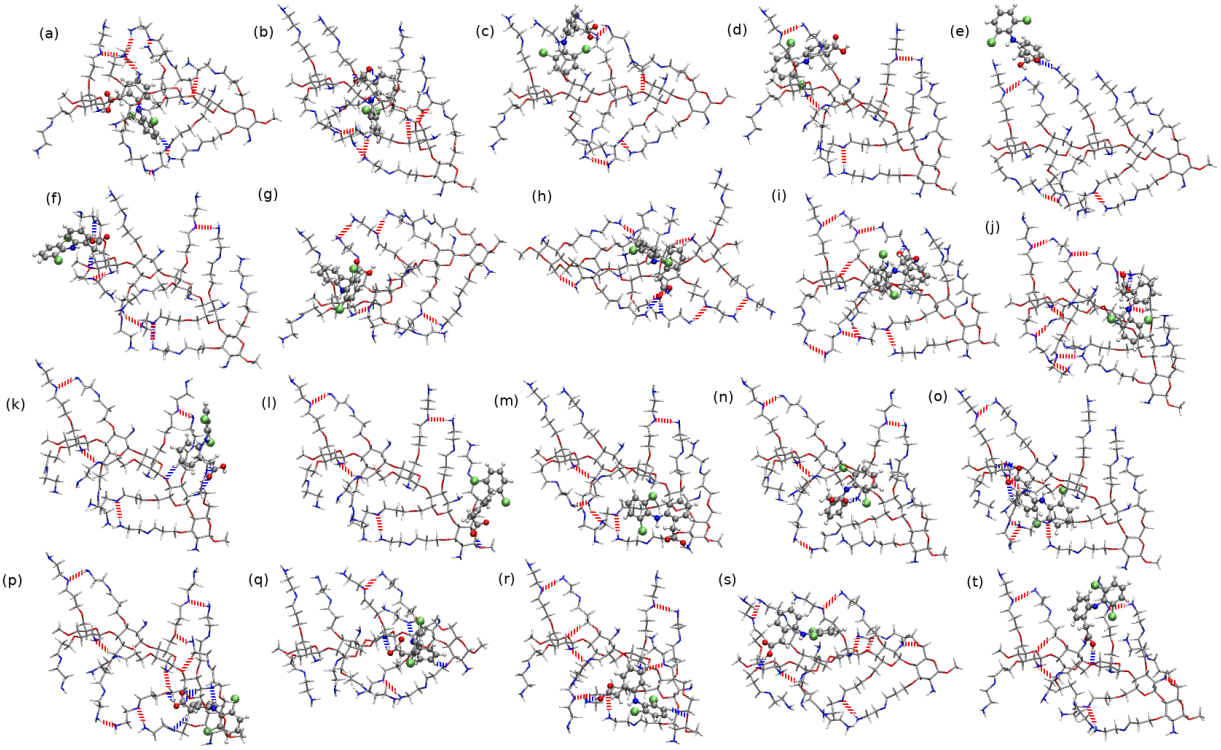

Figure S16: Optimized structures of $CS5(NH_2)_2$:DFH complexes (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10**, (k) **11**, (l) **12**, (m) **13-PT**, (n) **14**, (o) **15**, (p) **16**, (q) **17**, (r) **18**, (s) **19**, (t) **20**. Dashed lines depict hydrogen bonds (blue: intermolecular, green: intramolecular in DFH, red: intramolecular in $CS5(NH_2)_2$). $CS5(NH_2)_2$ presented in licorice representation and DFH with balls.

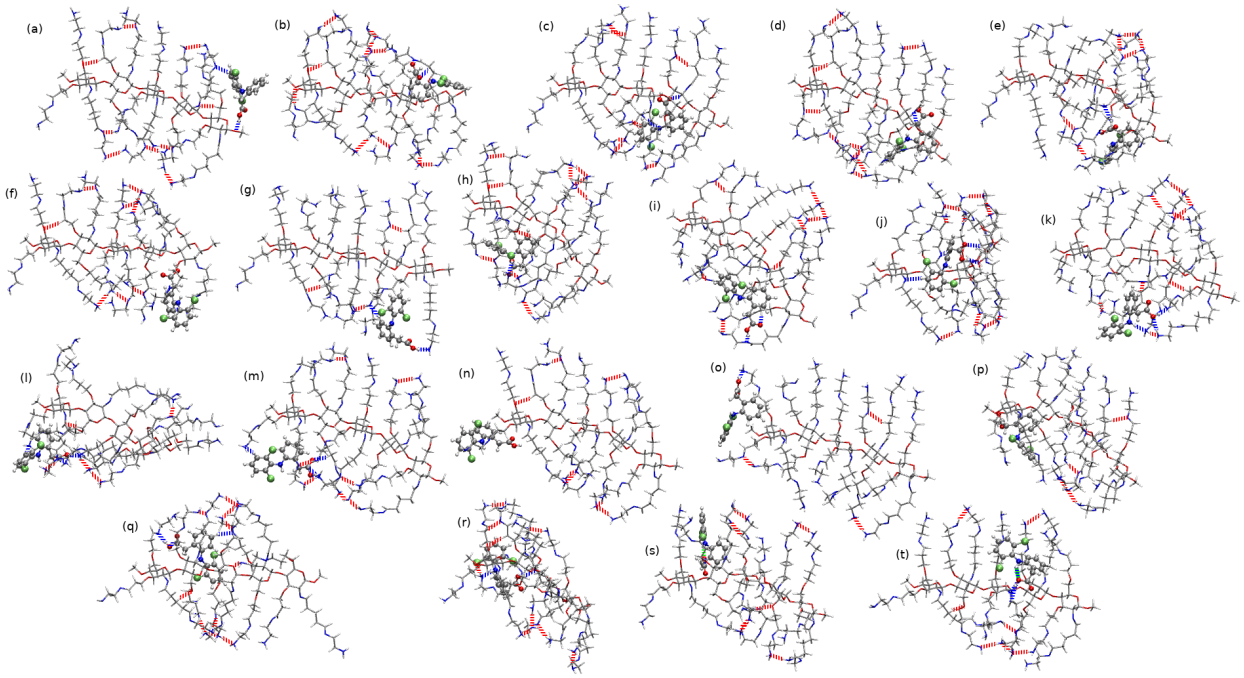

Figure S17: Optimized structures of $CS5(NH_2)_3$:DFH complexes (a) **1**, (b) **2**, (c) **3**, (d) **4**, (e) **5**, (f) **6**, (g) **7**, (h) **8**, (i) **9**, (j) **10**, (k) **11**, (l) **12**, (m) **13-PT**, (n) **14**, (o) **15**, (p) **16**, (q) **17**, (r) **18**, (s) **19**, (t) **20**. Dashed lines depict hydrogen bonds (blue: intermolecular, green: intramolecular in DFH, red: intramolecular in $CS5(NH_2)_3$). $CS5(NH_2)_3$ presented in licorice representation and DFH with balls.

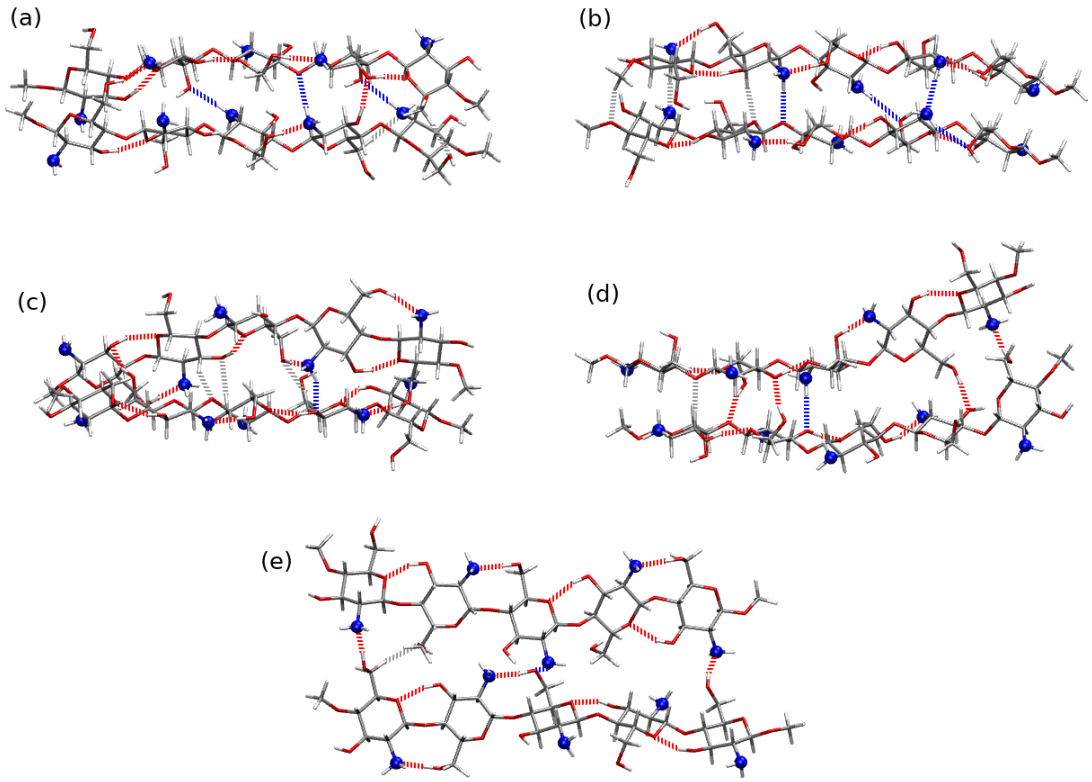

Figure S18: Optimized structures of the pristine $\left[CS5\right]_2$ dimers. Blue balls represent nitrogen atoms of the original amino groups close to the polymer backbone.

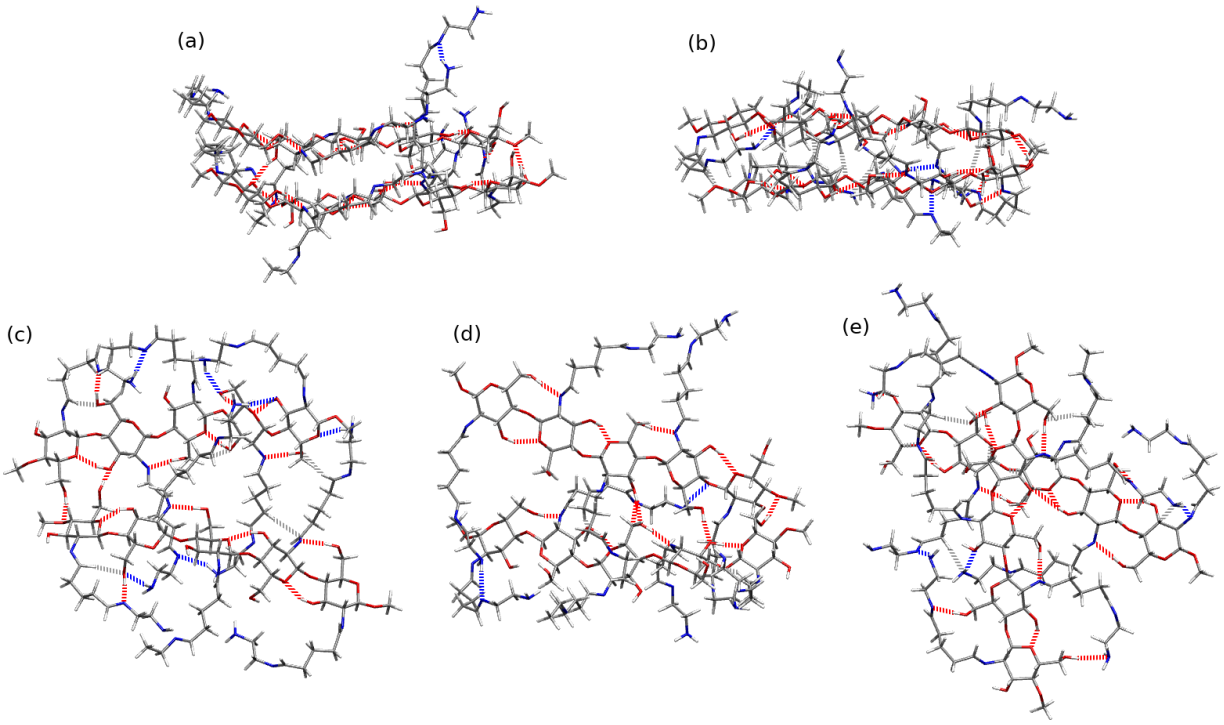

Figure S19: Optimized structures of $\left[CS5(NH_2)\right]$ dimers

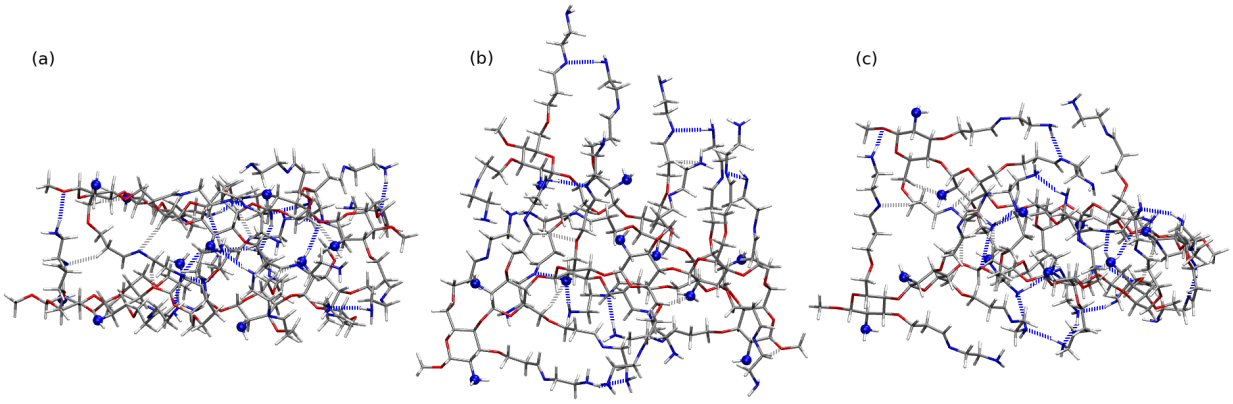

Figure S20: Optimized structures of $\left[CS5(NH_2)_2\right]_2$ dimers. Blue balls represent nitrogen atoms of the original amino groups close to the polymer backbone.

Table S2: Intramolecular N-H...O hydrogen bond parameters

System	H...O	N...O	N-H	∡N-H...O	∡H-N...O
DFNa					
1	1.68	2.66	1.05	155.0	15.5
2	3.07	3.21	1.02	88.7	72.8
3	1.90	2.83	1.03	147.5	21.2
4	1.78	2.72	1.03	149.0	19.7
5	1.74	2.71	1.04	153.6	16.6
6	1.87	2.81	1.03	148.5	20.4
7	1.81	2.73	1.03	146.9	21.2
7a	1.93	2.92	1.03	161.2	12.2
8	1.80	2.72	1.04	146.4	21.4
9	1.71	2.70	1.04	156.4	14.7
10	1.84	2.73	1.03	141.5	24.9
DF^-					
2	1.59	2.62	1.07	158.5	12.9
3	3.97	4.37	1.02	106.6	60.4
4	1.54	2.58	1.08	160.8	11.3
6	1.59	2.63	1.07	160.2	11.9
7a	4.41	4.05	1.02	62.9	104.2
8	1.52	2.57	1.08	161.6	10.7
9	1.59	2.63	1.07	160.2	11.9
DFH					
2	3.56	3.68	1.02	88.3	75.6
3	5.39	4.68	1.02	41.9	129.7
4	1.86	2.75	1.02	144.0	23.4
5	2.09	2.92	1.02	136.9	29.3
6	1.95	2.89	1.02	151.2	19.0
7	2.00	2.90	1.02	144.7	23.6
8	2.18	3.10	1.02	149.8	20.7
9	1.94	2.88	1.02	151.1	19.0

Table S3: Intramolecular N-H...Cl hydrogen bond parameters

System	H...Cl	N...Cl	N-H	∡N-H...Cl	∡H-N...Cl
DFNa					
1	2.64	3.03	1.05	149.7	58.5
2	2.49	3.01	1.02	110.5	51.0
3	2.74	3.03	1.03	96.2	64.0
4	2.63	3.02	1.03	102.6	57.9
5	2.64	3.04	1.04	103.0	57.6
6	2.57	3.03	1.03	106.3	54.5
7	3.08	2.97	1.03	74.1	86.4
7a	2.70	3.05	1.03	99.7	60.9
8	3.07	2.99	1.03	75.7	84.7
9	2.68	3.02	1.04	98.5	61.5
10	2.97	2.97	1.03	80.0	80.0
DF^-					
2	2.73	2.99	1.07	93.7	65.4
3	2.54	3.03	1.02	109.0	52.3
4	2.75	3.00	1.08	92.5	66.4
6	2.78	3.02	1.07	92.5	66.7
7a	2.39	3.01	1.02	118.5	44.2
8	2.74	3.00	1.08	92.8	66.1
9	2.78	3.02	1.07	92.5	66.7
DFH					
2	2.46	2.98	1.02	111.4	50.0
3	2.46	3.03	1.02	114.8	47.4
4	2.60	3.01	1.02	103.4	57.3
5	2.52	3.01	1.02	108.9	52.4
6	2.68	3.01	1.02	99.0	61.4
7	2.47	2.99	1.02	110.5	50.8
8	2.71	3.03	1.02	98.1	62.4
9	2.64	3.02	1.02	101.7	58.9

Table S4: SAPT0 interaction energy components for the CS5:DFH (boldfaced most attractive SAPT0 interaction; boxes for ELST/DISP ratio smaller than 0.59, denoting dispersion-dominated systems and underlined energies for ELST/DISP ratio exceeding 1.7, denoting electrostatic-dominated systems)

System	ELST	EXCH	IND	DISP	SCS-DISP	HF	SAPT0	SCS-SAPT0	ELST/DISP	ELST/SCS-DISP
cc-pVDZ										
1	-46.51	67.06	-18.82	-32.73	-25.41	1.73	**-31.00**	-23.68	1.42	1.83
2	-31.31	44.20	-13.73	-20.38	-15.80	-0.85	-21.23	-16.64	1.54	1.98
3	-13.17	22.73	-3.63	-17.08	-13.21	5.93	-11.15	-7.28	0.77	1.00
4	-12.30	20.59	-3.84	-16.21	-12.52	4.44	-11.77	-8.07	0.76	0.98
5	-20.03	34.73	-5.73	-28.08	-21.69	8.97	-19.11	-12.72	0.71	0.92
6	-11.49	23.11	-3.04	-20.44	-15.78	8.58	-11.86	-7.20	0.56	0.73
7	-9.06	18.34	-2.78	-14.81	-11.43	6.49	-8.32	-4.94	0.61	0.79
8	-8.93	20.10	-2.15	-13.33	-10.28	9.02	-4.31	-1.26	0.67	0.87
9	-26.50	39.45	-8.55	-21.83	-16.90	4.40	-17.43	-12.50	1.21	1.57
10	-42.14	58.91	-24.07	-21.75	-16.93	-7.31	**-29.06**	-24.24	1.94	2.49
aug-cc-pVDZ										
1	-45.25	66.73	-19.84	-43.04	-33.68	1.65	**-41.39**	-32.03	1.05	1.34
2	-30.83	44.02	-14.37	-28.04	-21.90	-1.18	-29.22	-23.08	1.10	1.41
3	-12.66	22.53	-3.91	-22.83	-17.81	5.96	-16.88	-11.85	0.55	0.71
4	-11.91	20.50	-3.92	-21.61	-16.83	4.67	-16.94	-12.16	0.55	0.71
5	-19.44	34.53	-5.93	-38.39	-29.91	9.16	-29.24	-20.76	0.51	0.65
6	-11.11	22.86	-3.18	-28.44	-22.13	8.56	-19.88	-13.57	0.39	0.50
7	-8.72	18.29	-3.01	-20.45	-15.92	6.55	-13.90	-9.36	0.43	0.55
8	-8.69	20.05	-2.27	-18.27	-14.21	9.08	-9.19	-5.13	0.48	0.61
9	-25.67	39.18	-9.01	-29.80	-23.25	4.51	-25.29	-18.75	0.86	1.10
10	-41.22	58.69	-25.03	-28.92	-22.66	-7.57	**-36.49**	-30.23	1.43	1.82

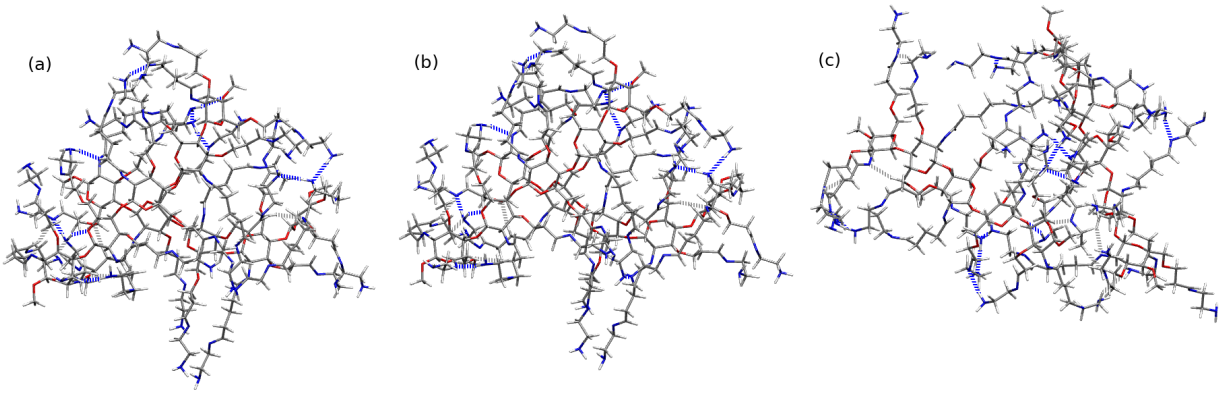

Figure S21: Optimized structures of $\left[CS5(NH_2)_3\right]_2$ dimers