Heat Capacities of Uracil, Thymine, and Its Alkylated, Cyclooligomethylenated, and Halogenated Derivatives by Differential Calorimetry

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The molar heat capacity (C_p) of solid uracil, its alkylated and halogenated derivatives, and cyclooligomethylenouracils in the temperature range of (298.15 to 343.15) K by a differential scanning calorimeter (SETARAM TG-DSC 111) were determined. It was demonstrated that the C_p value increases by increasing the number of methylene groups attached to the diketopyrimidine ring. The correlations $C_p = f(T)$ are given. The contributions of C−CH$_3$, N−CH$_3$, and C−NO$_2$ groups as well as F, Cl, Br, and I atoms in the value of C_p for the temperature of 298.15 K are presented. The Chickos method for calculation of C_p values is discussed.

Introduction

Thermodynamic properties of uracil and thymine (Figure 1) and its alkylated, halogenated, amino, and nitro derivatives and cyclooligomethylenouracils were the subject of our previous research.[1−11] The enthalpy of solvatation based on the experimentally determined enthalpy of solution ($\Delta_{sol}H_m°$) at 298.15 K and the van't Hoff enthalpy of sublimations $\Delta_{sub}H_m$ were determined. These measurements were made in aqueous solutions for 39 compounds and in methanol and *N*,*N*-dimethylformamide solutions for 14 compunds. The values of partial molar volumes (V_2^0) and partial molar heat capacities ($C_{p,2}^0$) of aqueous solutions were made for 44 derivatives of nucleic acid bases; whereas in methanol solutions they were determined for 20 compounds. Experimental data of these investigations have been presented before.[9−11]

The aim of this work is to enlarge the scope of study by determination of the heat capacity of these compounds. In these investigations, the same samples of compounds derivatives were used as in earlier studies.

Materials and Methods

The object of our study was 28 compounds. Some of them were obtained from specialized chemical companies and used without further purification. Uracil, 3-methyluracil, 5-methyluracil (thymine), 6-methyluracil, 1,3-dimethyluracil, 5-fluorouracil, 5-chlorouracil, and 5-bromouracil of minimum 99 % purity were purchased from Sigma Chemical Co Ltd. 1-Methyluracil and 5-(trifluoromethyl)uracil, both of 97 % purity, were supplied by Aldrich Chemicals Co. Ltd. 5-Nitrouracil (> 97 % purity) was supplied by Fluka Chemicals, and 5-iodouracil (> 98 % purity) was supplied by Avocado Research Chemicals Ltd.

A significant number of substances used were individually synthesized in the Department of Organic Chemistry (Military Academy of Medicine, Łódź, Poland) headed by Prof. Dramiński, namely, 1,5-dimethyluracil, 1,6-dimethyluracil, 3,6-dimethyluracil, 5,6-dimethyluracil, 1,3,6-trimethyluracil, 1,3,5,6-tetramethyluracil, 1,3-dimethyl-5-ethyluracil, 1,3-dimethyl-5-propyluracil, 1,3-dimethyl-5-butyluracil, 1,3-dimethyl-6-ethyluracil, 1,3-dimethyl-6-propyluracil, 1,3-dimethyl-6-butyluracil, 1,3-dimethyl-5,6-trimethyleneuracil, 1,3-dimethyl-5,6-tetramethyleneuracil, and 1,3-dimethyl-5,6-pentamethyleneuracil. All of these compounds were thoroughly purified by repeated crystallization or repeated vacuum sublimation. Their purity was checked by melting point determinations and chromatographic analyses in several solvents systems as described previously.[5] Purity of these compounds was determined as 99.8 %.

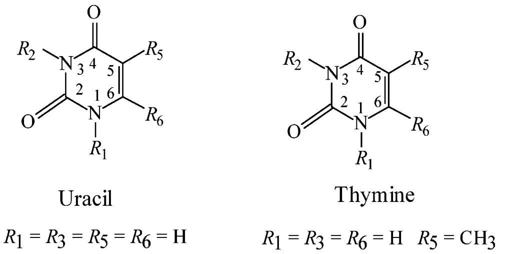

Figure 1. Structural formulas of uracil and thymine.

The C_p determinations were made with use of a Calvet TG-DSC 111 differential scanning microcalorimeter (Setaram, France). The measurements were performed differentially, relative to the empty crucible in the range (298.15 to 343.15) K with the scan rate of 0.5 K·min^{-1}. All the samples were prepared in the same way. The investigated compounds were placed in stainless steal crucibles of the total volume of 150 μL. The stainless steal cover was crimped with an aluminum seal with use of a crimping press.

The DSC device was calibrated using benzoic acid samples (no. 19.A.3, 99.8 %, received from the Central Office of Measures, Department of Analytical Chemistry, Łódź, Poland, Polish Committee for Standardization) as a standard substance. The obtained C_p value of benzoic acid of (146.9 ± 0.8) J·mol^{-1}·K^{-1} is in good agreement with the value recommended by IUPAC[12] (146.8 J·mol^{-1}·K^{-1}). The experimentally determined C_p values in the temperature range (298.15 to 343.15) K were approximated by the expression $C_p = f(T)$.

The contributions of C−CH$_3$ and N−CH$_3$ groups in the C_p values at 398.15 K were calculated using the general additivity scheme, according to the equation:

$$C_p = C_{p,0} + \sum_i n_i C_{p,i} \tag{1}$$

where $C_{p,0}$ is a constant, $C_{p,i}$ is the additive value of molar heat

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Table 1. Experimental (C_p(ex)) and Approximated (C_p(appr)) Value of Molar Heat Capacity and the Correlation Functions of Uracil and Its Derivatives

no.	T/K	$C_p(\mathrm{ex})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	$C_p(\mathrm{appr})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	no.	T/K	$C_p(\mathrm{ex})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	$C_p(\mathrm{appr})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	no.	T/K	$C_p(\mathrm{ex})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	$C_p(\mathrm{appr})/\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$
1	Uracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 119.3(1.5) + 0.58(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.4$			**2**	1-Methyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 101.4(0.8) + 2.22(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.7$			**3**	3-Methyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 100.8(1.3) + 2.29(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.2$		
	298.15	131.8	133.7		298.15	156.9	156.8		298.15	157.0	158.0
	303.15	135.5	136.6		303.15	167.2	167.9		303.15	168.8	169.4
	308.15	140.9	139.5		308.15	179.6	178.9		308.15	181.2	180.9
	313.15	143.0	142.3		313.15	190.9	190.0		313.15	193.0	192.3
	318.15	146.1	145.2		318.15	200.5	201.1		318.15	206.1	203.8
	323.15	149.0	148.1		323.15	211.1	212.2		323.15	214.3	215.2
	328.15	151.8	151.0		328.15	223.0	223.2		328.15	226.1	226.7
	333.15	154.3	153.9		333.15	235.0	234.3		333.15	239.2	238.1
	338.15	156.8	156.8		338.15	245.9	245.4		338.15	249.0	249.5
	343.15	157.4	159.6		343.15	256.1	256.5		343.15	260.2	261.0
4	5-Methyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 139.0(1.5) + 0.99(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.3$			**5**	6-Methyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 146.2(0.8) + 0.68(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.8$			**6**	1,3-Dimethyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 170.0(0.5) + 0.5(0.01)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.4$		
	298.15	163.0	163.9		298.15	162.5	163.2		298.15	182.5	183.0
	303.15	168.2	168.9		303.15	167.2	166.5		303.15	185.4	185.7
	308.15	173.7	173.8		308.15	170.2	169.9		308.15	188.7	188.3
	313.15	178.7	178.8		313.15	172.2	173.3		313.15	191.2	190.9
	318.15	184.3	183.8		318.15	176.9	176.7		318.15	193.8	193.5
	323.15	189.9	188.7		323.15	181.4	180.1		323.15	196.4	196.1
	328.15	195.2	193.7		328.15	183.0	183.5		328.15	199.1	198.7
	333.15	200.0	198.7		333.15	187.3	186.9		333.15	201.0	201.4
	338.15	203.5	203.6		338.15	190.4	190.3		338.15	203.3	204.0
	343.15	205.9	208.6		343.15	193.0	193.7		343.15	206.8	206.6
7	3,6-Dimethyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 176.9(0.5) + 0.5(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.3$			**8**	1,6-Dimethyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 158.5(2.5) + 1.1(0.05)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 2.3$			**9**	1,5-Dimethyluracyl $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 177.6(0.8) + 0.4(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.7$		
	298.15	187.4	187.3		298.15	188.1	186.5		298.15	187.6	187.6
	303.15	193.1	189.7		303.15	194.3	192.1		303.15	190.0	189.5
	308.15	191.4	192.1		308.15	197.9	197.7		308.15	190.3	191.5
	313.15	193.5	194.5		313.15	202.6	203.3		313.15	194.1	193.5
	318.15	198.4	197.0		318.15	206.8	208.9		318.15	194.8	195.5
	323.15	200.3	199.4		323.15	211.0	214.5		323.15	198.5	197.5
	328.15	202.4	201.8		328.15	217.9	220.1		328.15	199.2	199.4
	333.15	203.8	204.2		333.15	225.1	225.6		333.15	202.0	201.4
	338.15	206.0	206.6		338.15	233.1	231.2		338.15	203.0	203.4
	343.15	209.0	209.0		343.15	239.8	236.8		343.15	205.2	205.4
10	5,6-Dimethyluracyl $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 170.7(1.3) + 0.9(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.2$			**11**	1,3,6-Trimethyluracyl $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) =195.2(0.6) + 2.2(0.04)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 2.0$			**12**	1,3,5,6-Tetramethyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 218.1(2.1) + 0.99(0.04)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.9$		
	298.15	191.1	193.2		298.15	212.6	210.3		298.15	244.5	242.9
	303.15	198.3	197.7		303.15	213.5	213.3		303.15	248.8	247.9
	308.15	203.2	202.2		308.15	217.1	216.3		308.15	254.0	252.9
	313.15	208.0	206.7		313.15	218.5	219.3		313.15	256.5	257.8
	318.15	212.0	211.2		318.15	219.8	222.3		318.15	260.9	262.8
	323.15	215.6	215.6		323.15	223.4	225.3		323.15	266.7	267.8
	328.15	219.1	220.1		328.15	228.3	228.3		328.15	271.2	272.8
	333.15	223.3	224.6		333.15	229.0	231.4		333.15	276.6	277.7
	338.15	229.3	229.1		338.15	236.5	234.4		338.15	282.3	282.7
	343.15	234.1	233.6		343.15	239.6	237.4		343.15	291.5	287.7
13	1,3-Dimethyl-5-etyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 220.0(2.8) + 0.97(0.06)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 2.5$			**14**	1,3-Dimethyl-5-*n*-propyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 295.9(2.5) + 0.22(0.07)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.4$			**16**	1,3-Dimethyl-6-ethyluracil $C_p\ /(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 225(6.2) + 0.6(0.16)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 3.4$		
	298.15	241.1	244.2		298.15	302.7	301.5		298.15	241.8	240.0
	303.15	250.1	249.0		303.15	302.7	302.6		303.15	243.4	243.0
	308.15	256.5	253.8		308.15	302.8	303.7		308.15	245.3	246.0
	313.15	261.0	258.7		313.15	303.0	304.9		313.15	246.3	248.9
	318.15	264.3	263.5		318.15	306.2	306.0		318.15	248.3	251.9
	323.15	267.4	268.3		323.15	308.4	307.1		323.15	259.6	254.9
	328.15	270.7	273.2	**15**	1,3-Dimethyl-5-*n*-butyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 37.2(0.0) - 572.4(0.0)\ (T/\mathrm{K}\ -273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.0$						
	333.15	275.2	278.0								
	338.15	281.7	282.8								
	343.15	291.1	287.6		298.15	358.1	358.2				
					303.15	544.2	544.2				
17	1,3-Dimethyl-6-*n*-propyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 271.2(5.3) + 0.57(0.14)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 2.9$			**18**	1,3-Dimethyl-6-butyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 287.8(0.1) + 0.33(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.6$			**19**	1,3-Dimethyl-5,6-trimethyleneuracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 230.9(2.6) + 0.9(0.09)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.6$		
	298.15	287.2	285.6		298.15	296.4	296.1		298.15	252.9	253.2
	303.15	288.8	288.4		303.15	297.9	297.8		303.15	258.1	257.6
	308.15	290.5	291.3		308.15	299.4	299.5		308.15	261.8	262.1
	313.15	292.2	294.2		313.15	300.9	301.2				
	318.15	293.9	297.1		318.15	302.1	302.8				
	323.15	303.9	299.9		323.15	305.3	304.5				

Table 1. (Continued)

no.	T K	C_p(ex) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	C_p(appr) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	no.	T K	C_p(ex) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	C_p(appr) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	no.	T K	C_p(ex) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$	C_p(appr) $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$
20	1,3-Dimethyl-5,6-tetramethyleneuracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 246.9(2.1) + 1.45(0.05)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.1$			**21**	1,3-Dimethyl-5,6-pentamethyleneuracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 286.6(1.6) + 1.19(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.5$			**22**	6-Chlorouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 134.8(1.0) + 0.18(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.9$		
	298.15	282.9	283.0		298.15	314.5	316.3		298.15	139.4	139.2
	303.15	291.2	290.3		303.15	321.6	322.2		303.15	141.0	140.1
	308.15	296.2	297.5		308.15	329.0	328.2		308.15	141.2	141.0
	313.15	305.8	304.8		313.15	333.6	334.1		313.15	140.8	141.9
	318.15	310.9	312.0		318.15	341.1	340.0		318.15	141.3	142.8
	323.15	319.8	319.2		323.15	347.9	346.0		323.15	144.7	143.7
					328.15	353.3	351.9		328.15	144.9	144.6
					333.15	358.4	357.8		333.15	145.1	145.5
					338.15	363.2	363.8		338.15	146.0	146.3
					343.15	367.3	369.7		343.15	147.9	147.2
23	5-Fluorouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 128.3(1.4) + 0.33(0.03)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 1.3$			**24**	5-Chlorouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 124.9(0.8) + 0.46(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.7$			**25**	5-Bromouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 132.9 + 0.47(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.9$		
	298.15	138.3	136.7		298.15	136.7	136.5		298.15	144.7	144.7
	303.15	139.1	138.3		303.15	137.9	138.8		303.15	147.9	147.0
	308.15	140.0	140.0		308.15	142.1	141.1		308.15	148.5	149.3
	313.15	140.9	141.7		313.15	142.9	143.4		313.15	151.0	151.7
	318.15	142.0	143.3		318.15	146.1	145.7		318.15	153.9	154.0
	323.15	143.6	145.0		323.15	147.2	148.0		323.15	157.1	156.4
	328.15	145.5	146.7		328.15	151.2	150.4		328.15	157.9	158.7
	333.15	147.9	148.3		333.15	152.9	152.7		333.15	162.0	161.1
	338.15	150.6	150.0		338.15	154.9	155.0		338.15	164.3	163.4
	343.15	153.8	151.7		343.15	157.0	157.3		343.15	164.8	165.8
26	5-Iodouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 137.0(0.7) + 0.57(0.01)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.6$			**27**	5-Trifluoromethyluracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 168.4(0.8) + 0.54(0.02)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.8$			**28**	5-Nitrouracil $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 163.4(0.5) + 0.17(0.01)\ (T/\mathrm{K}\ 273.15)$ $\mathrm{rmsd}/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 0.4$		
	298.15	150.9	151.1		298.15	182.2	181.9		298.15	167.2	167.5
	303.15	153.9	154.0		303.15	183.9	184.6		303.15	167.9	168.4
	308.15	156.8	156.8		308.15	188.1	187.3		308.15	169.9	169.2
	313.15	159.8	159.7		313.15	190.3	190.1		313.15	169.9	170.0
	318.15	162.8	162.5		318.15	192.2	192.8		318.15	171.1	170.9
	323.15	165.8	165.3		323.15	195.9	195.5		323.15	171.8	171.7
	328.15	168.6	168.2		328.15	198.2	198.2		328.15	173.0	172.5
	333.15	170.3	171.0		333.15	199.4	200.9		333.15	173.1	173.4
	338.15	172.7	173.8		338.15	204.4	203.6		338.15	174.5	174.2
	343.15	177.5	176.7		343.15	206.6	206.3		343.15	174.5	175.1

capacity for group i, and n_i is the number of type N$-$CH$_3$ or C$-$CH$_3$ groups. The $C_{p,0}$ and $C_{p,i}$ values were estimated by using the multiple regression routine (Excel 2003, Microsoft).

The experimentally determined C_p values at 298.15 K were also compared with those estimated by the Chickos and Acree group additivity model.[13] The C_p value of uracil was accepted as being equal to 127.8 $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$ assuming that it corresponds to the sum of the contents of two cyclic secondary groups $-$CONH$-$ and two tertiary aromatics sp^2 C groups $=$CH$-$.

Results and Discussion

The C_p data of particular compounds determined by continuous DSC method and the correlations $C_p = f(T)$ are given in Table 1. As it is shown in Figure 2, for the majority of compounds under study there exists a linear dependence between the C_p values and the number (n) of $-$CH$_2-$ groups at 298.15 K. This correlation was not fulfilled by the thymine series derivatives with elongated alkyl side chains.

The variation of $C_p = f(n{-}CH_2{-})$ is expressed by the relation: $C_p/(\mathrm{J\cdot mol^{-1}\cdot K^{-1}}) = 129.62 + 27.90\ (n{-}CH_2{-})$ with rmsd $= 1.4\ \mathrm{J\cdot mol^{-1}\cdot K^{-1}}$. In the case of cyclooligomethylene derivatives of uracil (Figure 3) the linearity is maintained, but the values of C_p are lower than those for methylated and alkylated ones. This is probably due to more compact structures of these compounds because that hydrocarbonated ring induces constraints in a molecule's freedom degrees.[3]

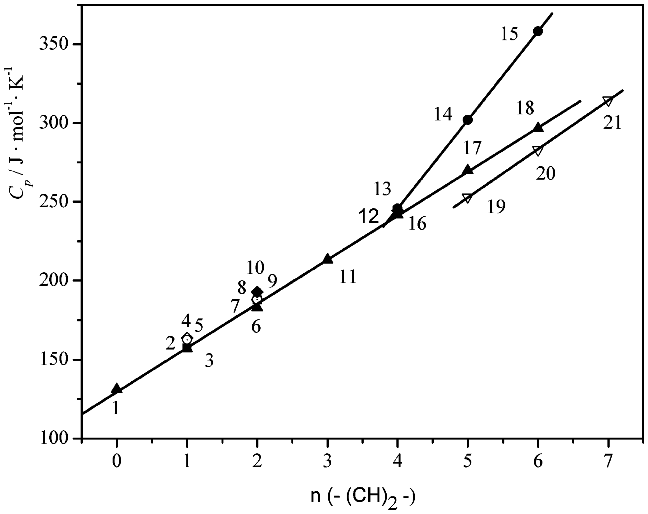

Figure 2. Molar heat capacities (C_p) of solid alkyluracils against the number of carbon alkyls groups (n). The number of compound corresponds to Table 2.

The increments of C_p per $-$CH$_2-$ in cyclooligomethyleneuracils are equal to 30.7 $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$. This value is close to C$-$CH$_3$ contributions in the C_p value of methylated and alkylated uracils (30.4 $\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$). The same trends were also observed for apparent molar heat capacities and partial molar

Table 2. Molar Heat Capacities Data of Derivatives of Uracil at 298.15 K

no.	compound	C_p(ex)[a] $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$	C_p(appr)[a] $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$	C_p[b] $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$	C_p[c] $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$	C_p(appr) − C_p[c] $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$
1	uracil	131.8	134.6	131.8	127.8	6.8
2	1-methyluracil	156.9	156.7	157.3	153.5	3.2
3	3-methyluracil	157.0	158.4	157.3	153.5	4.9
4	5-methyluracil	163.0	164.0	162.6	155.4	8.6
5	6-methyluracil	162.5	163.3	162.6	155.4	7.9
6	1,3-dimethyluracil	182.5	183.0	182.7	179.2	3.8
7	3,6-dimethyluracil	187.4	187.3	188.0	181.8	5.5
8	1,6-dimethyluracil	188.1	189.7	188.0	181.8	7.9
9	1,5-dimethyluracyl	187.6	187.5	188.0	181.8	5.7
10	5,6-dimethyluracyl	191.1	193.3	193.4	183.0	10.3
11	1,3,6-trimethyluracil	212.6	213.1	213.5	206.8	6.3
12	1,3,5,6-tetramethyluracil	244.5	242.8	244.4	234.4	8.4
13	1,3-dimethyl-5-etyluracil	241.1	244.8	244.4	233.7	11.1
14	1,3-dimethyl-5-*n*-propyluracil	302.7	301.5	275.1	260.6	40.9
15	1,3-dimethyl-5-*n*-butyluracil	358.1	358.2	305.9	287.8	70.4
16	1,3-dimethyl-6-etyluracil	241.8	241.8	244.4	233.7	8.1
17	1,3-dimethyl-6-*n*-propyluracil	287.2	287.2	275.1	260.6	26.6
18	1,3-dimethyl-6-*n*-butyluracil	296.4	296.2	305.9	287.8	8.4
19	1,3- dimethyl-5,6-trimethyleneuracil	252.9	253.2	275.9	210.4	42.8
20	1,3-dimethyl-5,6-tetramethyleneuracil	282.9	282.9	305.9	235.0	47.9
21	1,3-dimethyl-5,6-pentamethyleneuracil	314.5	316.3	336.6	259.6	56.7
22	6-chlorouracil	139.4	139.6	139.4	147.5	−7.9
23	5-fluorouracil	138.3	136.6	138.3	143.6	−7.0
24	5-chlorouracil	136.7	136.6	139.4	147.5	−10.9
25	5-bromouracil	144.7	144.6	144.7	151.2	−6.6
26	5-iodouracil	150.9	151.1	149.8	146.7	4.4
27	5-trifluoromethyluracil	182.2	182.0	181.9	188.2	−6.2
28	5-nitrouracil	167.2	167.5	167.9	174.9	−7.4

[a] C_p(ex) and C_p(appr) see Table 1. [b] C_p values calculated by additivity scheme (see eq 1). [c] C_p values calculated using the Chickos and Acree group additivity method.

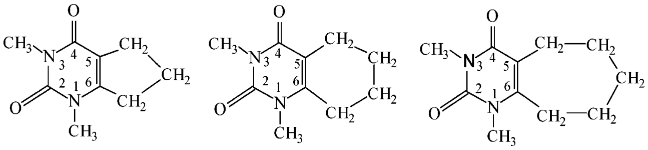

Figure 3. Structural formulas of cyclooligouracils: 1,3-dimethyl-5,6-trimethylenouracil; 1,3-dimethyl-5,6-tetramethylenouracil; and 1,3-dimethyl-5,6-pentamethylenouracil.

volumes in the case of alkylated and cyclooligomethylene derivatives of uracil in aqueous solutions.[3]

The C_p data at 298.15 K were analyzed in terms of general additivity scheme.[14] The C_p values of methylated uracils indicate that the contribution of $N-CH_3$ group differs markedly from the contributions of $C-CH_3$ group, but the ΔC_p values for 1-methyluracil and 3-methyluracil are almost the same, similarly as in the case of 5-methyluracil and 6-methyluracil. Taking into account the C_p values of all methylated uracils under study and those alkylated at C(6) (compounds **1**−**12** and **16**−**18** listed in Table 2), the calculated contributions of $C-CH_3$ group and $N-CH_3$ group are equal to (30.4 ± 1.1) $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$ and (25.9 ± 1.5) $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$, respectively, whereas the $C_{p,0}$ value is equal to (131.7 ± 2.1) $\mathrm{J{\cdot}mol^{-1}{\cdot}K^{-1}}$.

The experimental C_p data (Table 2) for 298.15 K were compared with those obtained by the Chickos[13] group additivity scheme for C_p of solid compounds at 298.15 K. The experimentally determined values of C_p and the C_p values calculated on the basis of group additivity method of uracil and its derivatives are collected in Table 2. These data are close to each other. The Chickos method of C_p determination at 298.15 K does not allow one to recognize the substituents position in the case of methylated uracils. On the contrary, the C_p values of alkylated (acyclic and cyclic) and halogenated derivatives of uracil are different for the same group located at other positions in diketopyrimidine ring in the uracil molecule.

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