Autorecycling Oxidation of Alcohols Catalysed by Pyridodipyrimidines as an NAD(P)$^+$ Model

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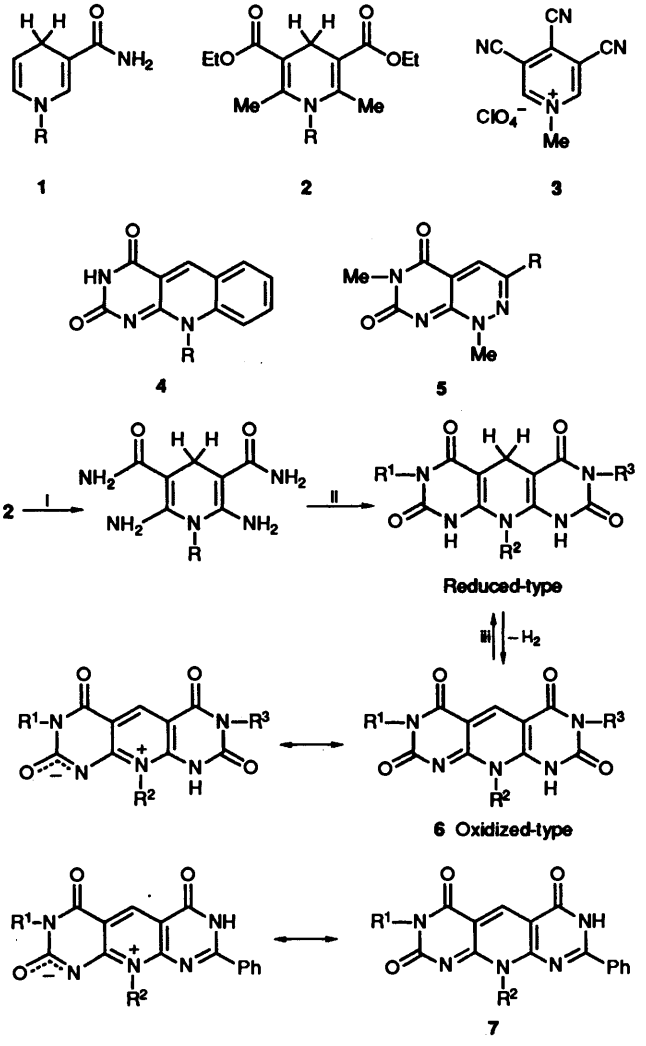
Two kinds of pyridodipyrimidines as new NAD-type redox catalysts, 3,7,10-trisubstituted pyrido-[2,3,-*d*:6,5-*d*']dipyrimidine-2,4,6,8(1*H*,3*H*,7*H*,10*H*)-tetraones **6** and 3,8,10-trisubstituted pyrido[2,3-*d*:6,5-*d*']dipyrimidine-2,4,6(3*H*,7*H*,10*H*)-triones **7**, have been synthesized by the condensation of 6-(substituted-amino)uracils **9** and 6-(substituted-amino)-2-phenylpyrimidin-4(3*H*)-ones **11** with appropriate 6-chloro-5-formyluracils **12** or 2,4,6-trichloropyrimidine-5-carbaldehyde **13** in dimethylformamide (DMF) or acetic acid. Compounds **6** and **7** have been found to oxidize a variety of alcohols under neutral conditions (in the absence of base) to yield the corresponding carbonyl compounds, catalytically with a markedly high turnover number. The oxidation yields were promoted remarkably depending upon the presence of lipophilic substituents, particularly due to the presence of longer alkyl group at the 10-position. These catalysts are so stable that the oxidation reaction proceeds until the substrate is exhausted.

The alcohol dehydrogenases catalysing the interconversion between carbonyl compounds and alcohols require NAD(P)$^+$/NAD(P)H as their coenzymes. In the biomimetic reactions, both classes of the *N*-substituted 1,4-dihydronicotinamides **1** and the Hantzsch esters **2** have been widely used as models of NAD(P)H.[1] However, there are few examples for the NAD(P)$^+$ model oxidation of alcohol substrates,[2–5] because thermodynamically the redox equilibrium favours the formation of the pyridinium ion. Furthermore these model oxidations of alcohols proceded only with the aid of very strong base and gave the carbonyl compounds in stoichiometric yields. Exceptionally, Wallenfels and Hanstein[2] reported the oxidation of fluorenol to fluorenone by 3,4,5-tricyano-*N*-methylpyridinium perchlorate **3** under neutral conditions. Although this unusual NAD(P)$^+$ model has very high electron affinity by virtue of the three cyano groups, the yield of fluorenone was still only 8%.

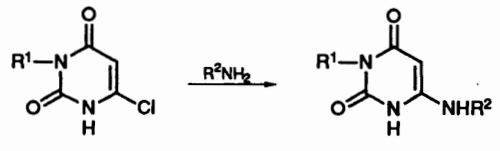
We have reported that 5-deazaflavins **4**[6] and their analogues such as 4-deazatoxoflavins **5**[7] were considered to be NAD(P)$^+$ models which oxidized alcohols under weakly basic conditions and thereupon exhibited some recycling in the oxidation giving carbonyl compounds in more than 100% yield. Nevertheless, owing to the presence of base in the reaction mixture, simultaneous decomposition of the 5-deazaflavins and their analogues occurred to some extent. Therefore, prolonged use of 5-deazaflavins and their analogues in the oxidation reaction was difficult.

Therefore, there has been a need for more efficient oxidation catalysts which act without any base. As candidate compounds, pyridodipyrimidines (PPs) **6** and **7** have been designed (Scheme 1). The PPs are structurally cyclized compounds of the amino analogues of the Hantzsch esters **2** and also have a conjugated system similar to that of 5-deazaflavins **4**. Furthermore one of the canonical forms can be regarded as a model of the nicotinamide nucleotide protected by annelation ('masked NAD$^+$ analogue').

In 1981, we reported in a preliminary communication[8] that the PPs **6** and **7** as new NAD-type redox catalysts oxidized various alcohols under neutral conditions and thereupon exhibited remarkable autorecycling. That was the first example



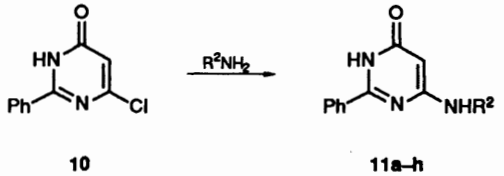
Scheme 1 *Reagents and conditions:* i, Amination, then amidation; ii, cyclization; iii, H_2



8a–c **9a–s**

a; R^1 = H
b; R^1 = Me
c; R^1 = Ph

a; $R^1 = R^2$ = Me
b; R^1 = Me, R^2 = Et
c; R^1 = Me, R^2 = Bu
d; R^1 = Me, R^2 = $Me[CH_2]_7$
e; R^1 = Me, R^2 = $Me[CH_2]_{11}$
f; R^1 = Me, R^2 = $Me[CH_2]_{17}$
g; R^1 = Me, R^2 = $Ph[CH_2]_2$
h; R^1 = Me, R^2 = Ph
i; R^1 = Me, R^2 = 4-MeC_6H_4
j; R^1 = Me, R^2 = 4-ClC_6H_4
k; R^1 = Me, R^2 = 4-BrC_6H_4
l; R^1 = Me, R^2 = 3,4-$Me_2C_6H_3$
m; $R^1 = R^2$ = Ph
n; R^1 = Ph, R^2 = 4-MeC_6H_4
o; R^1 = Ph, R^2 = 4-ClC_6H_4
p; R^1 = Ph, R^2 = 3,4-$Me_2C_6H_3$
q; R^1 = H, R^2 = $Me[CH_2]_7$
r; R^1 = H, R^2 = $Me[CH_2]_{11}$
s; R^1 = H, R^2 = $Me[CH_2]_{17}$



10 **11a–h**

a; R^2 = Me
b; R^2 = Et
c; R^2 = Pr
d; R^2 = Bu
e; R^2 = $Me[CH_2]_7$
f; R^2 = $Me[CH_2]_{11}$
g; R^2 = $Me[CH_2]_{17}$
h; R^2 = $Ph[CH_2]_2$

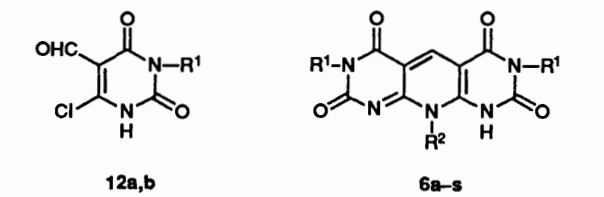
of the efficient autorecycling oxidation of alcohols by the coenzyme model *under neutral conditions*.

In this paper, we present a full account of the preparation of a series of the PPs and their autorecycling oxidation of alcohols. The influence of the introduced substituents upon the autorecycling oxidation activities of the PPs will be also discussed.

Results and Discussion

Synthesis of Pyridodipyrimidines **6** *and* **7**.—The requisite starting materials, 6-alkylaminouracils **9a–g**, **q–s** and 6-arylaminouracils **9h–p** were prepared according to the literature.[9–14] Namely, the reaction of 3-substituted (or 3-unsubstituted) 6-chlorouracils **8a–c** with an appropriate alkylamine in butan-1-ol or arylamine without solvent under heating gave the corresponding aminouracils **9a–s** (Table 1). Other starting materials, 6-alkylamino-2-phenylpyrimidin-4(3*H*)-ones **11a–h**, were prepared by the reaction of 6-chloro-2-phenylpyrimidin-4(3*H*)-one[15] **10** with appropriate alkylamines in butan-1-ol (Table 2).

Heating of the amino derivatives **9a–s** and **11a–h** thus obtained with 6-chloro-5-formyluracils **12a,b**[16] or 2,4,6-trichloropyrimidine-5-carbaldehyde **13**[16] in DMF or acetic acid gave the corresponding pyridodipyrimidines **6a–s** and **7a–o**. Compounds **7p–r** bearing long alkyl chains at the 3- and 10-position on the ring were synthesized by the reaction of 10-octadecyl-8-phenylpyrido[2,3-*d*:6,5-*d*']dipyrimidine-2,4,6-



12a,b **6a–s**

a; R^1 = Me
b; R^1 = Ph

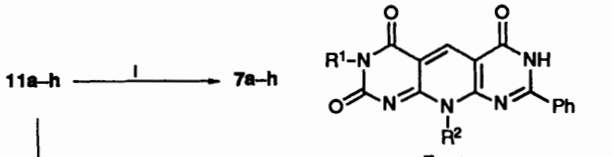
9a–s → **6a–p**

6q–s

13

a; $R^1 = R^2$ = Me
b; R^1 = Me, R^2 = Et
c; R^1 = Me, R^2 = Bu
d; R^1 = Me, R^2 = $Me[CH_2]_7$
e; R^1 = Me, R^2 = $Me[CH_2]_{11}$
f; R^1 = Me, R^2 = $Me[CH_2]_{17}$
g; R^1 = Me, R^2 = $Ph[CH_2]_2$
h; R^1 = Me, R^2 = Ph
i; R^1 = Me, R^2 = 4-MeC_6H_4
j; R^1 = Me, R^2 = 4-ClC_6H_4
k; R^1 = Me, R^2 = 4-BrC_6H_4
l; R^1 = Me, R^2 = 3,4-$Me_2C_6H_3$
m; $R^1 = R^2$ = Ph
n; R^1 = Ph, R^2 = 4-MeC_6H_4
o; R^1 = Ph, R^2 = 4-ClC_6H_4
p; R^1 = Ph, R^2 = 3,4-$Me_2C_6H_3$
q; R^1 = H, R^2 = $Me[CH_2]_7$
r; R^1 = H, R^2 = $Me[CH_2]_{11}$
s; R^1 = H, R^2 = $Me[CH_2]_{17}$

Scheme 2



11a–h → **7a–h** (I)

7l–o (II)

7o → **7p–r** (III)

7a–r

a; $R^1 = R^2$ = Me
b; R^1 = Me, R^2 = Et
c; R^1 = Me, R^2 = Pr
d; R^1 = Me, R^2 = Bu
e; R^1 = Me, R^2 = $Me[CH_2]_7$
f; R^1 = Me, R^2 = $Me[CH_2]_{11}$
g; R^1 = Me, R^2 = $Me[CH_2]_{17}$
h; R^1 = Me, R^2 = $Ph[CH_2]_2$
i; R^1 = H, R^2 = Me
j; R^1 = H, R^2 = Et
k; R^1 = H, R^2 = Pr
l; R^1 = H, R^2 = Bu
m; R^1 = H, R^2 = $Me[CH_2]_7$
n; R^1 = H, R^2 = $Me[CH_2]_{11}$
o; R^1 = H, R^2 = $Me[CH_2]_{17}$
p; R^1 = Bu, R^2 = $Me[CH_2]_{17}$
q; R^1 = $Me[CH_2]_7$, R^2 = $Me[CH_2]_{17}$
r; $R^1 = R^2$ = $Me[CH_2]_{17}$

Scheme 3 *Reagents:* i, **12a**; ii, **13**; iii, R^1Br.

(3*H*,7*H*,10*H*)-trione **7o** with the appropriate alkyl bromide in the presence of potassium carbonate in hexamethylphosphoric triamide (HMPA) (Schemes 2 and 3). The structures of PPs **6a–s** and **7a–r** thus prepared were established on the basis of their satisfactory analytical and spectral data and, particularly, by the presence of the characteristic singlet signal for the C-5 proton at δ_H 9.5–9.9 region in the ^1H NMR spectrum (Tables 3–5).

Synthesis of 1,5-*Dihydropyridodipyrimidines* **14** *and* **15**.—The PPs **6** and **7** in aq. ammonia were easily reduced by sodium dithionite to afford the corresponding 5,10-dihydro-PPs (see Scheme 4). Some dihydro-PPs **14a–e** and **15** were isolated, as described in Table 6 and the Experimental section. Compounds **14** and **15** showed a characteristic singlet signal for the two C-5 protons at $\delta_H \sim 3.6$–3.9 in the ^1H NMR spectrum (Table 5). Mass spectra also supported the structural assignment for the products **14** and **15** as 5,10-dihydro compounds.

Table 1 Analytical data for 6-alkyl- and 6-aryl-aminouracils **9a–s**

Compd.	Yield (%)	M.p.[a] (°C)	Recrystn. solvent	ν_{max} (Nujol) (cm^{-1})	Formula	Found (%) (Required) C	H	N
9a[b]	51	301–302	water	3360 (NH); 1722, 1690 (C=O)	$C_6H_9N_3O_2$			
9b[c]	88	276–278	water	3260 (NH); 1722sh, 1713 (C=O)	$C_7H_{11}N_3O_2$			
9c[b]	66	242–244	water	3340 (NH); 1732, 1680 (C=O)	$C_9H_{15}N_3O_2$			
9d	84	214	DMF	3335 (NH); 1734, 1680 (C=O)	$C_{13}H_{23}N_3O_2$	61.6 (61.6)	9.2 (9.15)	16.4 (16.6)
9e	92	212–213	EtOH	3330 (NH); 1740, 1682 (C=O)	$C_{17}H_{31}N_3O_2$	66.2 (66.0)	10.2 (10.1)	13.4 (13.6)
9f	83	192–193	EtOH	3340 (NH); 1738, 1680 (C=O)	$C_{23}H_{43}N_3O_2$	70.5 (70.2)	11.3 (11.0)	10.7 (10.7)
9g[d]	87	238	EtOH	3240 (NH); 1718, 1700sh (C=O)	$C_{13}H_{15}N_3O_2$			
9h[e]	81	336–338	DMF	3230 (NH); 1720, 1698sh (C=O)	$C_{11}H_{11}N_3O_2$			
9i[f]	89	323–325	EtOH	3230 (NH); 1725 (C=O)	$C_{12}H_{13}N_3O_2$			
9j[g]	74	295–297	DMF	3340 (NH); 1738, 1700 (C=O)	$C_{11}H_{10}ClN_3O_2$			
9k	78	>300	DMF	3350 (NH); 1737, 1702 (C=O)	$C_{11}H_{10}BrN_3O_2$	44.8 (44.6)	3.5 (3.4)	14.1 (14.2)
9l[g]	89	276–278	EtOH	3225 (NH); 1718 (C=O)	$C_{13}H_{15}N_3O_2$			
9m[e]	70	308–310	EtOH	3260 (NH); 1730, 1720 (C=O)	$C_{16}H_{13}N_3O_2$			
9n	83	>300	EtOH	3260 (NH); 1722, 1710 (C=O)	$C_{17}H_{15}N_3O_2$	69.65 (69.6)	5.25 (5.15)	14.3 (14.3)
9o	77	312 (decomp.)	EtOH	3320 (NH); 1738sh, 1710 (C=O)	$C_{16}H_{12}ClN_3O_2$	61.2 (61.25)	3.9 (3.9)	13.4 (13.4)
9p	81	287–289	EtOH	3290 (NH); 1720, 1710sh (C=O)	$C_{18}H_{17}N_3O_2$	70.45 (70.3)	5.6 (5.6)	13.4 (13.7)
9q	83	278–279	DMF	3220 (NH); 1703 (C=O)	$C_{12}H_{21}N_3O_2$	60.5 (60.2)	9.1 (8.85)	17.35 (17.6)
9r	87	274	EtOH	3220 (NH); 1718 (C=O)	$C_{16}H_{29}N_3O_2$	65.3 (65.05)	10.1 (9.9)	13.9 (14.2)
9s	91	156–157	EtOH	3250 (NH); 1738, 1720sh (C=O)	$C_{22}H_{41}N_3O_2$	69.6 (69.6)	11.1 (10.9)	11.1 (11.1)

[a] All compounds were obtained as powders or prisms. [b] Ref. 9. [c] Ref. 10. [d] Ref. 11. [e] Ref. 12. [f] Ref. 13. [g] Ref. 14.

Table 2 Analytical data for 6-alkylamino-2-phenylpyrimidin-4(3*H*)-ones **11a-h**

Compd.	Yield (%)	M.p.[a] (°C)	ν_{max}(Nujol) (cm^{-1})	Formula	Found (%) (Required) C	H	N
11a	97	269–270	3420 (NH); 1640 (C=O)	$C_{11}H_{11}N_3O$	65.5 (65.65)	5.4 (5.5)	20.7 (20.9)
11b	96	202	3410 (NH); 1640 (C=O)	$C_{12}H_{13}N_3O$	67.3 (66.95)	6.0 (6.1)	19.5 (19.5)
11c	91	163	3415 (NH); 1635 (C=O)	$C_{13}H_{15}N_3O$	67.9 (68.1)	6.55 (6.6)	18.1 (18.3)
11d	94	160–161	3400 (NH); 1635 (C=O)	$C_{14}H_{17}N_3O$	69.2 (69.1)	7.0 (7.0)	17.3 (17.3)
11e	65	112–113	3340 (NH); 1635 (C=O)	$C_{18}H_{25}N_3O$	71.9 (72.2)	8.4 (8.4)	14.0 (14.0)
11f	69	126–127	3300 (NH); 1630 (C=O)	$C_{22}H_{33}N_3O$	74.2 (74.3)	9.5 (9.4)	11.65 (11.8)
11g	92	122	3300 (NH); 1630 (C=O)	$C_{28}H_{45}N_3O$	76.6 (76.5)	10.4 (10.3)	9.5 (9.6)
11h	75	87–88	3280 (NH); 1625 (C=O)	$C_{18}H_{17}N_3O$	74.0 (74.2)	6.2 (5.9)	14.1 (14.4)

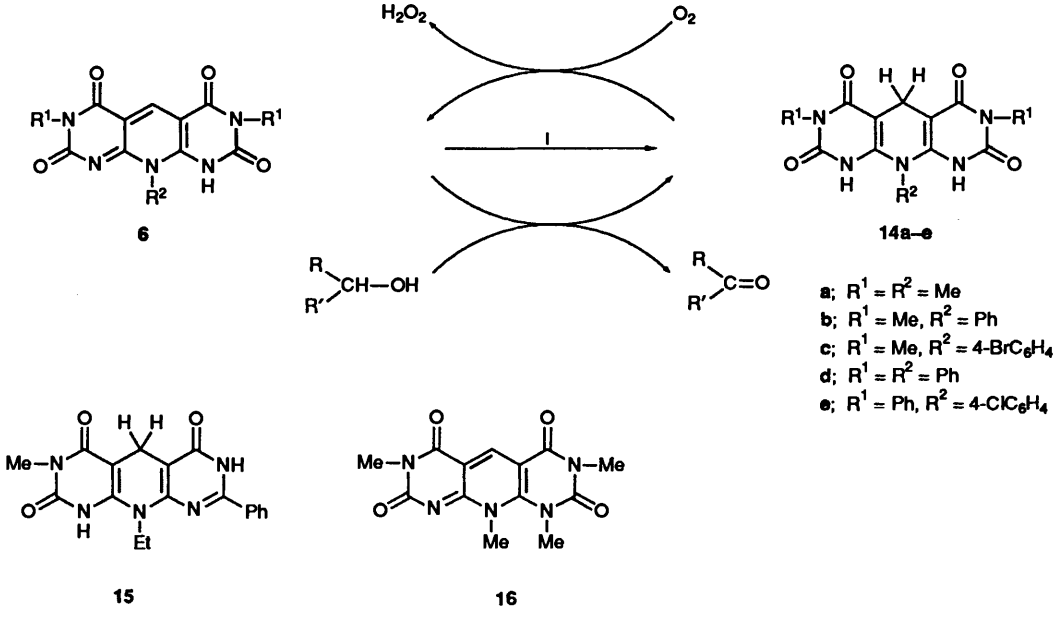
[a] All compounds were recrystallized from EtOH and obtained as powders or prisms.

Oxidation of Alcohols with 2,4,6,8-Tetraoxopyridodipyrimidines **6**.—As expected, the PPs **6** showed generally strong oxidizing power toward benzyl alcohol and cyclohexanol under neutral conditions to yield the corresponding carbonyl compounds. Moreover, a remarkable autorecycling in the oxidation was observed. Table 7 shows the results of autorecycling oxidation of benzyl alcohol (2 cm^3) and cyclohexanol (2 cm^3) by 3,7,10-trisubstituted-2,4,6,8-tetraoxo-PPs **6** (0.04 mmol) at 90 °C for 25 h. As the alkyl chain length was increased at the 10-position, the compound's oxidation ability was apparently

Table 3 Analytical data for 10-substituted 2,4,6,8-tetraoxopyridodipyrimidines **6a–s**

Starting materials	Product	Yield (%)	M.p.[a] (°C)	Recrystn. solvent	ν_{max}(KBr) (cm^{-1}) C=O	Formula	Found (%) (Required) C	H	N
9a + **12a**	**6a**[b]	80	>300	AcOH	1748, 1695, 1660, 1618	$C_{12}H_{11}N_5O_4$			
9b + **12a**	**6b**	75	>330	AcOH	1752, 1693, 1660, 1618	$C_{13}H_{13}N_5O_4$	51.4 (51.5)	4.35 (4.3)	22.9 (23.1)
9c + **12a**	**6c**[b]	70	>330	AcOH	1742, 1698, 1650sh, 1635	$C_{15}H_{17}N_5O_4$			
9d + **12a**	**6d**[b]	72	219–220	ACOH	1735, 1700, 1665sh, 1620	$C_{19}H_{25}N_5O_4$			
9e + **12a**	**6e**[b]	78	205–206	AcOH	1732, 1702, 1690, 1620	$C_{23}H_{33}N_5O_4$			
9f + **12a**	**6f**	61	224	AcOH	1730, 1700, 1690, 1625	$C_{29}H_{45}N_5O_4$	66.1 (66.0)	8.9 (8.6)	13.5 (13.3)
9g + **12a**	**6g**	66	>330	AcOH	1742, 1690, 1675, 1610	$C_{19}H_{17}N_5O_4$	60.1 (60.15)	4.5 (4.5)	18.4 (18.5)
9h + **12a**	**6h**	74	>330	AcOH	1740, 1695, 1672, 1625	$C_{17}H_{13}N_5O_4$	58.0 (58.1)	3.7 (3.7)	19.75 (19.9)
9i + **12a**	**6i**	62	>330	AcOH	1738, 1700sh, 1674, 1620	$C_{18}H_{15}N_5O_4$	59.1 (59.2)	4.2 (4.1)	19.1 (19.2)
9j + **12a**	**6j**	75	>330	AcOH	1730, 1702, 1680, 1620	$C_{17}H_{12}ClN_5O_4$	53.0 (52.9)	3.1 (3.1)	18.0 (18.15)
9k + **12a**	**6k**	63	312	AcOH	1740, 1700sh, 1670, 1622	$C_{17}H_{12}BrN_5O_4$	47.3 (47.5)	2.7 (2.8)	16.1 (16.3)
9l + **12a**	**6l**	70	>330	AcOH	1740, 1695sh, 1672, 1620	$C_{19}H_{17}N_5O_4$	60.2 (60.15)	4.5 (4.5)	18.5 (18.5)
9m + **12b**	**6m**	85	310	EtOH	1724, 1680, 1630, 1618	$C_{27}H_{17}N_5O_4$	68.0 (68.2)	3.6 (3.6)	14.7 (14.7)
9n + **12b**	**6n**	70	268	DMF	1725, 1685, 1632, 1610	$C_{28}H_{19}N_5O_4$	68.7 (68.7)	4.0 (3.9)	14.3 (14.3)
9o + **12b**	**6o**	77	298	DMF	1725, 1682, 1640, 1612	$C_{27}H_{16}ClN_5O_4$	63.5 (63.6)	3.15 (3.2)	13.7 (13.7)
9p + **12b**	**6p**	69	273–274	EtOH	1725, 1680, 1645sh, 1618	$C_{29}H_{21}N_5O_4$	69.25 (69.2)	4.2 (4.2)	14.0 (13.9)
9q + **13**	**6q**	66	>330	DMF	1727, 1705, 1664, 1610	$C_{17}H_{21}N_5O_4$	56.6 (56.8)	5.9 (5.9)	19.4 (19.5)
9r + **13**	**6r**	78	>330	DMF	1725, 1700, 1660, 1612	$C_{21}H_{29}N_5O_4$	61.0 (60.7)	7.3 (7.0)	17.05 (16.9)
9s + **13**	**6s**	65	>330	DMF	1722, 1700, 1662, 1615	$C_{27}H_{41}N_5O_4$	65.2 (64.9)	8.1 (8.3)	14.1 (14.0)

[a] All compounds were obtained as pale yellow powders or needles. [b] Ref. 17.



Scheme 4 *Reagent:* i, $Na_2S_2O_4$

Table 4 Analytical data for 10-substituted 2,4,6-trioxo-8-phenylpyridodipyrimidines **7a–r**

Starting materials	Product	Yield (%)	M.p.[a] (°C)	Recrystn. solvent	Formula	Found (%) (Required) C	H	N
11a + **12a**	**7a**	55	>330	DMF	$C_{17}H_{13}N_5O_3$	60.8 (60.9)	3.9 (3.9)	20.7 (20.9)
11b + **12a**	**7b**	63	>330	DMF	$C_{18}H_{15}N_5O_3$	61.5 (61.9)	4.3 (4.3)	19.9 (20.05)
11c + 12a	**7c**	54	354	DMF	$C_{19}H_{17}N_5O_3$	62.4 (62.8)	4.7 (4.7)	19.0 (19.3)
11d + **12a**	**7d**	71	340	DMF	$C_{20}H_{19}N_5O_3$	63.5 (63.65)	5.2 (5.1)	18.8 (18.6)
11e + **12a**	**7e**	80	337	DMF	$C_{24}H_{27}N_5O_3$	66.2 (66.5)	6.2 (6.3)	16.0 (16.2)
11f + **12a**	**7f**	52	322	DMF	$C_{28}H_{35}N_5O_3$	69.0 (68.7)	7.2 (7.2)	14.2 (14.3)
11g + **12a**	**7g**	51	312	DMF	$C_{34}H_{47}N_5O_3$	71.3 (71.2)	8.3 (8.3)	12.1 (12.2)
11h + **12a**	**7h**	94	346	DMF	$C_{24}H_{19}N_5O_3$	67.5 (67.75)	4.6 (4.5)	16.2 (16.5)
11a + **13**	**7i**	83	>340	DMF	$C_{16}H_{11}N_5O_3$	59.6 (59.8)	3.6 (3.45)	22.0 (21.8)
11b + **13**	**7j**	45	>340	DMF	$C_{17}H_{13}N_5O_3$	61.0 (60.9)	3.7 (3.9)	20.7 (20.9)
11c + **13**	**7k**	57	>340	DMF	$C_{18}H_{15}N_5O_3$	61.8 (61.9)	4.4 (4.3)	19.9 (20.05)
11d + **13**	**7l**	68	336	DMF	$C_{19}H_{17}N_5O_3$	62.5 (62.8)	4.7 (4.7)	19.5 (19.3)
11e + **13**	**7m**	73	325	DMF	$C_{23}H_{25}N_5O_3$	65.8 (65.85)	5.65 (6.0)	16.7 (16.7)
11f + **13**	**7n**	68	330	DMF	$C_{27}H_{33}N_5O_3$	68.5 (68.2)	7.05 (7.0)	14.4 (14.7)
11g + **13**	**7o**	71	308	DMF	$C_{33}H_{45}N_5O_3$	70.6 (70.8)	8.4 (8.1)	12.7 (12.5)
7o	**7p**	74	174	EtOH	$C_{37}H_{53}N_5O_3$	72.3 (72.2)	8.6 (8.7)	11.2 (11.4)
7o	**7q**	60	137	EtOH	$C_{41}H_{61}N_5O_3$	73.0 (73.3)	8.8 (9.15)	10.7 (10.4)
7o	**7r**	61	155	EtOH	$C_{51}H_{81}N_5O_3$	75.7 (75.4)	10.1 (10.05)	8.8 (8.6)

[a] All compounds were obtained as yellow powders or prisms.

enhanced. In control experiments without the PPs **6** in the above alcohols, at most only a trace of carbonyl compounds was detected. Further, PPs **6** substituted with an aryl group at the 10-position exhibited more enhanced potency in the autorecycling oxidation than did PPs **6** substituted with an alkyl group. For instance, the oxidations of benzyl alcohol and cyclohexanol catalysed by compound **6a** ($R^1 = R^2 = Me$) at 90 °C for 25 h gave benzaldehyde in 1410% (based on catalyst) yield and cyclohexanone in 1580% (cat.) yield, respectively, whereas the oxidations catalysed by compound **6h** ($R^1 = Me$, $R^2 = Ph$) gave benzaldehyde in 2880% yield and cyclohexanone in 3090% yield, respectively. Among the PPs tested as oxidants, compounds **6i**, **6l**, **6n** and **6p** exhibited excellent autorecycling oxidation ability. In particular, compound **6l** showed catalytic action amounting to *ca.* 250 turnover * based on the catalyst and an oxidation yield of 51.4% based on the starting alcohol in the oxidation of cyclohexanol. These data suggested that increased lipophilicity of the C-10 substituent is important for increasing the autorecycling oxidation. Table 8 shows experimental results of the oxidation of cyclopentanol (3 cm^3) by 3,7,10-triaryl-2,4,6,8-tetraoxo-PPs **6m** and **6o** (1 and 15 mg, respectively) as catalyst at 115 °C for 25 h. As can be seen from Table 8, both compounds **6m** and **6o** showed very strong autorecycling oxidation toward cyclopentanol to give cyclopentanone. However, the yields based on the starting cyclopentanol were almost the same irrespective of the quantity of the catalyst used. Namely, the yields obtained with catalyst **6m** (1 mg, 2.1×10^{-3} mmol and 15 mg, 3.15×10^{-2} mmol) afforded cyclopentanone in 9.3 and 9.1%, respectively. The yields with catalyst **6o** were also similar. This fact suggests that 1 mg or less of the PP acted efficiently as a turnover catalyst under the conditions used.

On the other hand, 1,3,7,10-tetramethylpyrido[2,3-*d*:6,5-*d'*]dipyrimidine-2,4,6,8(1*H*,3*H*,7*H*,10*H*)-tetraone **16** (Scheme 4), a fully substituted PP, rarely oxidized alcohols under similar oxidation conditions. These results may indicate that the presence of acidic hydrogen (moving proton) on the nitrogen is of crucial importance for the PP catalysts to act as an autorecycling oxidizing agent. The fact that PPs **6q–s**, which have three acidic hydrogens, demonstrate stronger oxidation ability towards cyclopentanol and *l*-menthol seems to support the above hypothesis (Table 9). In contrast with PPs **6q–s**, compounds **6d–f** having only one acidic hydrogen exhibited very weak oxidizing ability particularly toward *l*-menthol. These observations might also be attributable to steric hindrance between the PP catalysts and *l*-menthol which has an isopropyl group.

The above autorecycling oxidation towards alcohols by PPs **6** means that these PPs oxidized alcohols rapidly under these conditions and the PPs themselves were reduced to the 5,10-dihydro-PPs **14**, which, however, were reoxidized slowly to the original PPs **6** by adventitious air. Thus the PPs **6** acts as a turnover catalyst as shown in Scheme 4. Some dihydro-PPs,

* ~25 000 Yield based on the catalyst. Turnover = % yield/100%.

Table 5 ^{1}H NMR spectroscopic data for the PPs **6a–s**, **7a–r**, **14a–e**, **15** and **16**

Compd.	δ_H(60 MHz; solvent CF_3CO_2D; standard Me_4Si)
6a	3.64 (6 H, s, 3- and 7-Me), 4.40 (3 H, s, 10-Me), 9.76 (1 H, s, 5-H)
6b	1.76 (3 H, t, *J* 7.0, CH_2*Me*), 3.64 (6 H, s, 3- and 7-Me), 4.91 (2 H, q, *J* 7.0, C*H*$_2$Me), 9.74 (1 H, s, 5-H)
6c	1.04 (3 H, t, *J* 7.0, CH_2*Me*), 1.85 (4 H, m, [C*H*$_2$]$_2$Me), 3.63 (6 H, s, 3- and 7-Me), 4.72 (2 H, m, NCH_2), 9.72 (1 H, s, 5-H)
6d	0.93 (3 H, t, *J* 7.0, CH_2*Me*), 1.41 (8 H, br s, [C*H*$_2$]$_4$*Me*), 1.84 (4 H, br, NCH_2[C*H*$_2$]$_2$), 3.65 (6 H, s, 3- and 7-Me), 4.55–5.00 (2 H, br, NCH_2), 9.74 (1 H, s, 5-H)
6e	0.90 (3 H, t, *J* 7.0, CH_2Me), 1.32 (16 H, br s, [C*H*$_2$]$_8$Me), 1.62–2.12 (4 H, br, NCH_2[C*H*$_2$]$_2$), 3.61 (6 H, s, 3- and 7-Me), 4.45–4.93 (2 H, br, NCH_2), 9.72 (1 H, s, 5-H)
6f	0.91 (3 H, t, *J* 7.0, CH_2*Me*), 1.33 (28 H, br s, [C*H*$_2$]$_{14}$Me), 1.65–2.10 (4 H, br, NCH_2(C*H*$_2$]$_2$), 3.54 (6 H, s, 3- and 7-Me), 4.55–4.98 (2 H, br, NCH_2), 9.53 (1 H, s, 5-H)
6g	3.38 (2 H, br t, *J* 5.9, NCH_2C*H*$_2$), 3.58 (6 H, s, 3- and 7-Me), 5.18 (2 H, br t, *J* 5.9, NCH_2), 6.90–7.10 (2 H, m, Ph), 7.18–7.38 (3 H, m, Ph), 9.72 (1 H, s, 5-H)
6h	3.60 (6 H, s, 3- and 7-Me), 7.43–7.78 (3 H, m, Ph), 7.84–8.07 (2 H, m, Ph), 9.87 (1 H, s, 5-H)
6i	2.64 (3 H, s, Ar*Me*), 3.60 (6 H, s, 3- and 7-Me), 7.49 (2 H, d, J_{AB} 8.5, ArH), 7.78 (2 H, d, J_{AB} 8.5, ArH), 9.86 (1 H, s, 5-H)
6j	3.59 (6 H, s, 3- and 7-Me), 7.61 (2 H, d, J_{AB} 8.8, ArH), 7.94 (2 H, d, J_{AB} 8.8, ArH), 9.85 (1 H, s, 5-H)
6k	3.60 (6 H, s, 3- and 7-Me), 7.53 (2 H, d, J_{AB} 8.8, ArH), 8.11 (2 H, d, J_{AB} 8.8, ArH), 9.86 (1 H, s, 5-H)
6l	2.47 (3 H, s, Ar*Me*), 2.54 (3 H, s, Ar*Me*), 3.60 (6 H, s, 3- and 7-Me), 7.31 (1 H, dd, $J_{2',5'}$ 2.2, $J_{5',6'}$ 8.2, 5′-H), 7.37 (1 H, d, $J_{2',5'}$ 2.2, 2′-H), 7.71 (1 H, d, $J_{5',6'}$ 8.2, 6′-H), 9.85 (1 H, s, 5-H)
6m	7.30–8.12 (15 H, m, 3 × Ph), 9.89 (1 H, s, 5-H)
6n	2.64 (3 H, s, Me), 7.15–7.94 (14 H, m, 2 × Ph and ArH), 9.88 (1 H, s, 5-H)
6o	7.24–7.70 (10 H, m, 2 × Ph), 7.60 (2 H, d, J_{AB} 8.8, ArH), 7.98 (2 H, d, J_{AB} 8.8, ArH), 9.89 (1 H, s, 5-H)
6p	2.52 (3 H, s, 4′-Me), 2.54 (3 H, s, 3′-Me), 7.70–7.31 (13 H, m, 2 × Ph and ArH), 9.89 (1 H, s, 5-H)
6q	0.92 (3 H, t, *J* 7.0, CH_2*Me*), 1.42 (8 H, br s, [C*H*$_2$]$_4$Me), 1.65–2.35 (4 H, br, NCH_2[C*H*$_2$]$_2$), 4.63–5.17 (2 H, m, NCH_2), 9.68 (1 H, s, 5-H)
6r	0.92 (3 H, t, *J* 7.0, CH_2*Me*), 1.34 (16 H, br s, [C*H*$_2$]$_8$Me), 1.60–2.40 (4 H, br, NCH_2[C*H*$_2$]$_2$), 4.50–5.13 (2 H, m, NCH_2), 9.67 (1 H, s, 5-H)
6s	0.91 (3 H, t, *J* 7.0, CH_2*Me*), 1.34 (28 H, br s, [C*H*$_2$]$_{14}$Me), 1.66–2.10 (4 H, m, NCH_2[C*H*$_2$]$_2$), 4.60–5.10 (2 H, br, NCH_2), 9.57 (1 H, s, 5-H)
7a	3.64 (3 H, s, 3-Me), 4.67 (3 H, s, 10-Me), 7.57–8.03 (3 H, m, Ph), 8.29–8.61 (2 H, m, Ph), 9.85 (1 H, s, 5-H)
7b	1.78 (3 H, t, *J* 7.0, CH_2*Me*), 3.67 (3 H, s, 3-Me), 5.28 (2 H, q, *J* 7.0, C*H*$_2$Me), 7.50–8.00 (3 H, m, Ph), 8.27–8.60 (2 H, m, Ph), 9.78 (1 H, s, 5-H)
7c	1.33 (3 H, t, *J* 7.0, CH_2*Me*), 1.77–2.43 (2 H, m, NCH_2C*H*$_2$), 3.62 (3 H, s, 3-Me), 4.93–5.33 (2 H, m, NCH_2), 7.53–7.97 (3 H, m, Ph), 8.27–8.60 (2 H, m, Ph), 9.80 (1 H, s, 5-H)
7d	1.17 (3 H, t, *J* 7.0, CH_2*Me*), 1.43–2.40 (4 H, m, [C*H*$_2$]$_2$Me), 3.67 (3 H, s, 3-Me), 4.83–5.50 (2 H, m, NCH_2), 7.47–8.00 (3 H, m, Ph), 8.23–8.63 (2 H, m, Ph), 9.83 (1 H, s, 5-H)
7e	0.93 (3 H, t, *J* 7.0, CH_2*Me*), 1.15–1.60 (8 H, br s, [C*H*$_2$]$_4$Me), 1.60–2.30 (4 H, br, NCH_2[C*H*$_2$]$_2$), 3.65 (3 H, s, 3-Me), 4.90–5.43 (2 H, m, NCH_2), 7.43–7.97 (3 H, m, Ph), 8.17–8.63 (2 H, m, Ph), 9.78 (1 H, s, 5-H)
7f	0.90 (3 H, t, *J* 7.0, CH_2*Me*), 1.10–1.60 (16 H, br s, [C*H*$_2$]$_8$Me), 1.60–2.20 (4 H, br, NCH_2[C*H*$_2$]$_2$), 3.65 (3 H, s, 3-Me), 4.93–5.43 (2 H, br, NCH_2), 7.50–8.00 (3 H, m, Ph), 8.23–8.58 (2 H, m, Ph), 9.80 (1 H, s, 5-H)
7g	0.92 (3 H, t, *J* 7.0, CH_2*Me*), 1.13–1.64 (28 H, br s, [C*H*$_2$]$_{14}$Me), 1.64–2.43 (4 H, br, NCH_2[C*H*$_2$]$_2$), 3.67 (3 H, s, 3-Me), 5.00–5.43 (2 H, m, NCH_2), 7.60–8.10 (3 H, m, Ph), 8.30–8.60 (2 H, m, Ph), 9.83 (1 H, s, 5-H)
7h	3.40 (2 H, br t, *J* 6.0, NCH_2C*H*$_2$), 3.63 (3 H, s, 3-Me), 5.57 (2 H, br t, *J* 6.0, NCH_2), 7.17 (5 H, s, CH_2CH_2*Ph*), 7.50–8.00 (3 H, m, 8-Ph), 8.30–8.60 (2 H, m, 8-Ph), 9.83 (1 H, s, 5-H)
7i	4.55 (3 H, s, Me), 7.45–7.90 (3 H, m, Ph), 8.20–8.55 (2 H, m, Ph), 9.75 (1 H, s, 5-H)
7j	1.82 (3 H, t, *J* 7.0, CH_2*Me*), 5.33 (2 H, q, *J* 7.0, C*H*$_2$Me), 7.57–8.12 (3 H, m, Ph), 8.27–8.73 (2 H, m, Ph), 9.83 (1 H, s, 5-H)
7k	1.34 (3 H, t, *J* 7.0, CH_2*Me*), 1.83–2.53 (2 H, m, NCH_2C*H*$_2$), 4.90–5.43 (2 H, m, NCH_2), 7.58–8.03 (3 H, m, Ph), 8.23–8.70 (2 H, m, Ph), 9.87 (1 H, s, 5-H)
7l	1.18 (3 H, t, *J* 7.0, CH_2*Me*), 1.47–2.50 (4 H, m, NCH_2[C*H*$_2$]$_2$), 4.90–5.60 (2 H, m, NCH_2), 7.57–8.13 (3 H, m, Ph), 8.25–8.67 (2 H, m, Ph), 9.82 (1 H, s, 5-H)
7m	0.92 (3 H, t, *J* 7.0, CH_2*Me*), 1.12–1.65 (8 H, br s, [C*H*$_2$]$_4$Me), 1,65–2.45 (4 H, br, NCH_2[C*H*$_2$]$_2$), 4.93–5.45 (2 H, br, NCH_2), 7.55–8.10 (3 H, m, Ph), 8.27–8.70 (2 H, m, Ph), 9.78 (1 H, s, 5-H)
7n	0.90 (3 H, t, *J* 7.0, CH_2Me), 1.10–1.64 (16 H, br s, [C*H*$_2$]$_8$Me), 1.64–2.50 (4 H, br, NCH_2[C*H*$_2$]$_2$), 4.95–5.40 (2 H, br, NCH_2), 7.50–7.95 (3 H, m, Ph), 8.20–8.55 (2 H, m, Ph), 9.73 (1 H, s, 5-H)
7o	0.90 (3 H, t, *J* 7.0, CH_2*Me*), 1.10–1.65 (28 H, br s, [C*H*$_2$]$_{14}$Me), 1.65–2.52 (4 H, br, NCH_2[C*H*$_2$]$_2$), 4.90–5.43 (2 H, br, NCH_2), 7.53–8.00 (3 H, m, Ph), 8.30–8.60 (2 H, m, Ph), 9.78 (1 H, s, 5-H)
7p	0.88 (3 H, t, *J* 7.0, 10-[CH_2]$_{17}$*Me*), 1.11 (3 H, t, *J* 7.0, 3-[CH_2]$_3$*Me*), 1.17–2.37 (36 H, br s, 10-CH_2[C*H*$_2$]$_{16}$ and 3-CH_2[C*H*$_2$]$_2$), 4.85–5.47 (4 H, br, 2 × NCH_2), 7.51–7.94 (3 H, m, Ph), 8.30–8.88 (2 H, m, Ph), 9.77 (1 H, s, 5-H)
7q	0.90 (6 H, m, 10-[CH_2]$_{17}$*Me* and 3-[CH_2]$_7$*Me*), 1.10–2.32 (44 H, br s, 10-CH_2[C*H*$_2$]$_{16}$ and 3-CH_2[C*H*$_2$]$_6$), 4.90–5.42 (4 H, br, 2 × NCH_2), 7.53–8.00 (3 H, m, Ph), 8.33–8.90 (2 H, m, Ph), 9.83 (1 H, s, 5-H)
7r	0.92 (6 H, m, 2 × [C*H*$_2$]$_{17}$Me), 1.10–2.43 (64 H, br s, 2 × [C*H*$_2$]$_{16}$Me), 4.94–5.50 (4 H, br, 2 × NCH_2), 7.57–7.92 (3 H, m, Ph), 8.67–8.93 (2 H, m, Ph), 9.85 (1 H, s, 5-H)
14a	3.53 (6 H, s, 3- and 7-Me), 3.60 (5 H, s, 2 × 5-H and 10-Me)
14b	3.48 (6 H, s, 3- and 7-Me), 3.57 (2 H, s, 2 × 5-H), 7.33–7.66 (3 H, m, Ph), 7.68–7.88 (2 H, m, Ph)
14c	3.48 (6 H, s, 3- and 7-Me), 3.69 (2 H, s, 2 × 5-H), 7.33 (2 H, d, J_{AB} 8.8, ArH), 7.93 (2 H, d, J_{AB} 8.8, ArH)
14d	3.74 (2 H, br s, 2 × 5-H), 7.13–7.96 (15 H, m, 3 × Ph)
14e	3.75 (2 H, br s, 2 × 5-H), 7.15–7.94 (14 H, m, 2 × Ph and ArH)
15	1.50 (3 H, t, *J* 7.1, CH_2*Me*), 3.55 (3 H, s, 3-Me), 3.85 (2 H, s, 2 × 5-H), 4.17–4.80 (2 H, q, *J* 7.1, C*H*$_2$Me), 7.38–7.88 (3 H, m, Ph), 8.02–8.31 (2 H, m, Ph)
16	3.66 (6 H, s, 3- and 7-Me), 3.94 (6 H, s, 9- and 10-Me), 9.40 (1 H, s, 5-H)

14a–e, were isolated from the reaction mixture and were identified by comparison with authentic samples unequivocally synthesized by the sodium dithionite reduction of PPs **6** (Table 6). To verify that the reduced catalysts **14** are indeed easily oxidized atmospherically to the oxidized-type catalysts **6** before the oxidation of alcohols occurs, the oxidation of alcohols with the dihydro-PPs **14a–e** as catalysts was carried out and afforded similar turnover numbers as with the PPs **6** as shown in Tables 7 and 8.

Fig. 1 shows the result of long-term oxidation of cyclopentanol (3 cm^3) by 3,7,10-triaryl-2,4,6,8-tetraoxo-PPs **6m** and **6o** (1 mg) at 115 °C. It would be interesting to know if the above

Table 6 Analytical data for 5,10-dihydro-2,4,6,8-tetraoxopyridodipyrimidines **14a–e**

Starting material	Product	Yield (%)	M.p.[a] (°C)	ν_{max}(KBr) (cm^{-1}) C=O	Formula	m/z M^+
6a	**14a**	91	>300	1703, 1655, 1625	$C_{12}H_{13}N_5O_4$	291
6h	**14b**	86	>300	1690, 1652, 1620	$C_{17}H_{15}N_5O_4$	353
6k	**14c**	90	>300	1703, 1660, 1620	$C_{17}H_{14}BrN_5O_4$	431/433
6m	**14d**	88	255–257	1702, 1655, 1635	$C_{27}H_{19}N_5O_4$	477
6o	**14e**	85	279–281	1710, 1655, 1630	$C_{27}H_{18}ClN_5O_4$	511/513

[a] All compounds were obtained as powders without recrystallization because of their instability in hot solvents.

Table 7 Autorecycling oxidation of benzyl alcohol (2 cm^3) and cyclohexanol (2 cm^3) by 2,4,6,8-tetraoxo-PPs **6** (0.04 mmol) and the dihydro derivatives **14** (0.04 mmol) at 90 °C for 25 h

	Substituent		Yield (%) of products	
Oxidant	R^1	R^2	Benzaldehyde	Cyclohexanone
6a	Me	Me	1 410[a] (2.9)[b]	1 580[a] (3.3)[b]
6b	Me	Et	1 470 (3.0)	1 750 (3.6)
6c	Me	Bu	1 830 (3.8)	3 250 (6.8)
6d	Me	$Me[CH_2]_7$	5 100 (10.6)	4 680 (9.7)
6g	Me	$Ph[CH_2]_2$	2 400 (5.0)	1 530 (3.2)
6h	Me	Ph	2 880 (6.0)	3 090 (6.4)
6i	Me	4-MeC_6H_4	3 240 (6.7)	8 600 (17.9)
6j	Me	4-ClC_6H_4	1 870 (3.9)	2 170 (4.5)
6k	Me	4-BrC_6H_4	3 490 (7.2)	4 320 (9.0)
6l	Me	3,4-$Me_2C_6H_3$	10 000 (20.7)	24 700 (51.4)
6m	Ph	Ph	4 860 (10.1)	7 510 (15.6)
6n	Ph	4-MeC_6H_4	11 400 (23.6)	22 400 (46.6)
6o	Ph	4-ClC_6H_4	6 290 (13.0)	12 400 (25.8)
6p	Ph	3,4-$Me_2C_6H_3$	14 200 (29.4)	22 900 (47.6)
14a	Me	Me		1 430 (3.0)
14b	Me	Ph		4 080 (8.5)
14c	Me	4-BrC_6H_4		5 170 (10.8)

[a] Yields based on the catalysts are given to three significant figures. [b] Yields based on the starting alcohols are given in parentheses.

Table 8 Autorecycling oxidation of cyclopentanol (3 cm^3) by 3,7,10-triaryl-2,4,6,8-tetraoxo-PPs **6m** and **6o** and the dihydro derivatives **14d** and **14e** at 115 °C for 25 h

			Amont of catalyst	
	Substituent		Yield (%) of cyclopentanone	
Oxidant	R^1	R^2	1 mg	15 mg
6m	Ph	Ph	146 000[a] (9.3)[b]	9 490[a] (9.1)[b]
6o	Ph	4-ClC_6H_4	180 000 (10.7)	11 900 (10.6)
14d	Ph	Ph	131 000 (8.3)	
14e	Ph	4-ClC_6H_4	142 000 (8.4)	

[a,b] As in Table 7.

Table 9 Autorecycling oxidation of cyclopentanol (3 cm^3) and *l*-menthol (3 g) by 10-alkyl-2,4,6,8-tetraoxo-PPs **6** (0.04 mmol) at 120 °C for 25 h

	Substituent		Yield (%) of products	
Oxidant	R^1	R^2	Cyclopentanone	*l*-Menthone
6d	Me	$Me[CH_2]_7$	4 770[a] (5.8)[b]	trace
6e	Me	$Me[CH_2]_{11}$	9 750 (11.8)	trace
6f	Me	$Me[CH_2]_{17}$	11 800 (14.3)	trace
6q	H	$Me[CH_2]_7$	9 120 (11.0)	5 010[a] (10.4)[b]
6r	H	$Me[CH_2]_{11}$	8 220 (9.9)	7 040 (14.7)
6s	H	$Me[CH_2]_{17}$	15 900 (19.2)	7 410 (15.4)

[a,b] As in Table 7.

oxidation proceeded essentially until the alcohol substrate was almost exhausted. The yield of cyclopentanone increases linearly with time for more than 150 h. After that, further oxidized products such as cyclopentenone or the illustrated ketal and hemiketal (see Fig. 1) are produced. Furthermore, it should be noted that the PP catalysts **6** used for the reactions can be recovered in high yield (70–95%) almost without having suffered any decomposition.

Oxidation of Alcohols with 2,4,6-Trioxo-8-phenylpyridodipyrimidines **7**.—Similarly, 2,4,6-trioxo-8-phenyl-PPs **7** oxidized several alcohols to give the corresponding carbonyl compounds, catalytically with a markedly high turnover number (Table 10). We concluded that those catalysts **7** which have more lipophilic substituents exhibited generally stronger oxidizing ability towards alcohols, in a similar manner as for 2,4,6,8-tetraoxo-PP catalysts **6**. As noted above, the appearance of stronger oxidizing ability in PPs **6** required not only increased lipophilicity of the catalyst **6** but also the presence of more acidic hydrogens on the ring. In the case of oxidation by 2,4,6-trioxo-8-phenyl-PPs **7**, however, the catalysts **7a**, **b**, **e–g** (R^1 = R^2 = alkyl) having only one acidic hydrogen exhibited stronger oxidizing ability than did the catalysts **7j**, **l–o** (R^1 = H, R^2 = alkyl) having two such hydrogens (see Table 10).

In conclusion, we have demonstrated the autorecycling oxidation of alcohols catalysed by two kinds of pyridodipyrimidines as new NAD-type redox catalysts under neutral conditions in a simple synthetic method. Therefore, the present method should be significant from the viewpoint of practical value as well as being of interest to synthetic organic chemists.

Experimental

M.p.s were determined on a Yanagimoto hot-stage apparatus and are uncorrected. IR spectra were recorded on a JASCO IRA-1 spectrometer. ^1H NMR spectra were measured at 60 MHz with a JEOL JNM 3H-60 spectrometer and at 200 MHz with a Varian VXR-200 spectrometer; tetramethylsilane was used as internal standard and *J*-values are given in Hz. Mass spectra were taken on a JEOL JMS OISG-2 instrument by direct insertion at 75 eV.

General Procedure for the Preparation of 6-Alkylaminouracils **9a–g**, **q–s**.—A mixture of a 6-chlorouracil **8a** or **8b** (6.82 mmol) with an appropriate alkylamine (13.6 mmol) in butan-1-ol (20 cm^3) was refluxed for 5 h. After cooling, the precipitated crystals were collected by filtration and recrystallized from water, ethanol, or DMF to give the corresponding *compounds* **9a–g**, **q–s** as powders or prisms (Table 1).

General Procedure for the Preparation of 6-Arylaminouracils **9h-p**.—A stirred mixture of a 6-chlorouracil **8b** or **8c** (30 mmol) with an appropriate arylamine (90 mmol) was heated at 160–170 °C for 10 min. After cooling, the mixture was diluted with diethyl ether to afford crystals, which were filtered off by suction, washed with water, and recrystallized from ethanol or

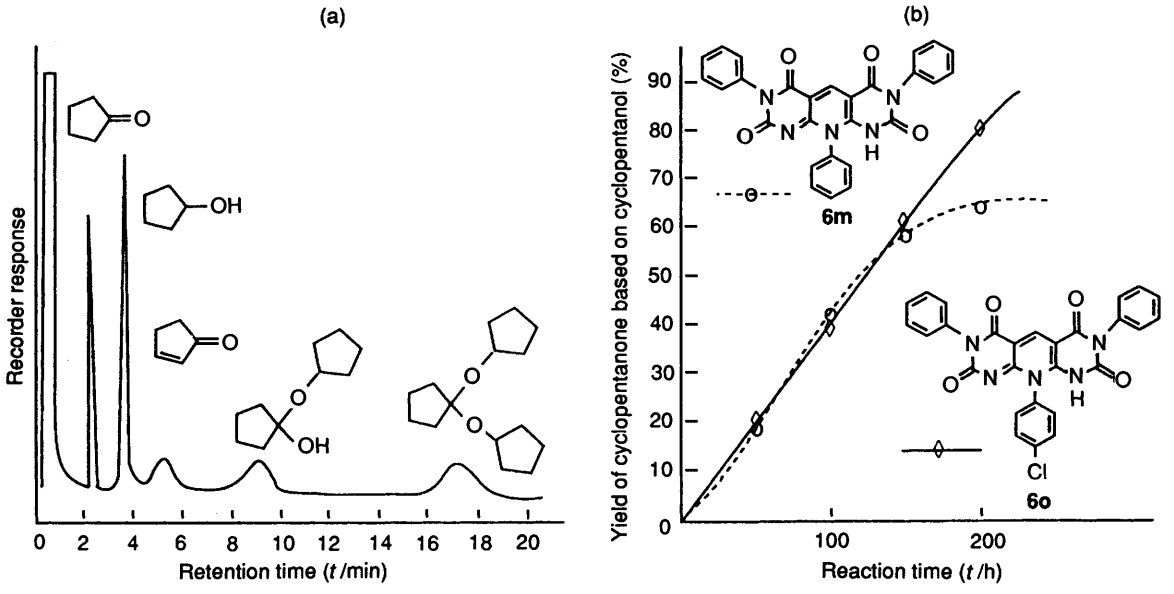


Figure 1 Autorecycling oxidation of cyclopentanol (3 cm^3) by 3,7,10-triaryl-2,4,6,8-tetraoxo-PPs (1 mg) at 115 °C. (a) Typical gas chromatogram of the oxidation products from cyclopentanol. (b) Yield of cyclopentanone upon oxidation of cyclopentanol with catalysts **6m** and **6o**.

Table 10 Autorecycling oxidation of cyclopentanol (3 cm^3) and *l*-menthol (3 g) by 10-alkyl-2,4,6-trioxo-8-phenyl-PPs **7** (0.04 mmol) at 120 °C for 25 h

	Substituent		Yield (%) of products	
Oxidant	R^1	R^2	Cyclopentanone	*l*-Menthone
7a	Me	Me	11 400[a] (13.8)[b]	2 780[a] (5.8)[b]
7b	Me	Et	11 300 (13.7)	3 300 (6.9)
7e	Me	$Me[CH_2]_7$	11 800 (14.3)	6 280 (13.1)
7f	Me	$Me[CH_2]_{11}$	15 900 (19.2)	9 550 (19.9)
7g	Me	$Me[CH_2]_{17}$	17 600 (21.3)	10 600 (22.1)
7j	H	Et	2 400 (2.9)	3 060 (6.4)
7l	H	Bu	3 690 (4.5)	3 800 (7.9)
7m	H	$Me[CH_2]_7$	5 060 (6.1)	6 700 (14.0)
7n	H	$Me[CH_2]_{11}$	4 660 (5.6)	5 270 (11.0)
7o	H	$Me[CH_2]_{17}$	4 480 (5.4)	7 080 (14.8)
7p	Bu	$Me[CH_2]_{17}$	11 800 (14.3)	
7q	$Me[CH_2]_7$	$Me[CH_2]_{17}$	19 700 (23.8)	
7r	$Me[CH_2]_{17}$	$Me[CH_2]_{17}$	11 000 (13.3)	

[a,b] As in Table 7.

DMF to give the corresponding *compounds* **9h–p** as prisms (Table 1).

General Procedure for the Preparation of 6-*Alkylamino*-2-*phenylpyrimidin*-4(3H)-*ones* **11a–h**.—A mixture of 6-chloro-2-phenylpyrimidin-4(3*H*)-one **10** (1 g, 4.84 mmol) with an appropriate alkylamine (10.6 mmol) in butan-1-ol (20 cm^3) was refluxed for 5 h. After cooling, the precipitated crystals were collected by filtration, washed with water, and recrystallized from ethanol to give the corresponding *compounds* **11a–h** as microcrystalline powders or prisms (Table 2).

General Procedure for the Preparation of 10-*Alkyl*-3,7-*dimethylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,8(1H,3H,7H,-10H)-*tetraones* **6a–g**.—A mixture of a 6-alkylamino-3-methyluracil **9a–g** (3 mmol) with 6-chloro-5-formyl-3-methyluracil **12a** (566 mg, 3 mmol) in acetic acid (5 cm^3) was refluxed for 4 h. The mixture was evaporated under reduced pressure and the residue was triturated in a small amount of ethanol. The precipitated crystals were collected by filtration and recrystallized from acetic acid to give the corresponding *products* **6a–g** as pale yellow microcrystalline powders or needles (Table 3).

General Procedure for the Preparation of 10-*Aryl*-3,7-*dimethylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,8(1H,3H,7H,-10H)-*tetraones* **6h–l**.—A mixture of a 6-arylamino-3-methyluracil **9h–l** (3 mmol) with 6-chloro-5-formyl-3-methyluracil **12a** (566 mg, 3 mmol) in DMF (5 cm^3) was refluxed for 5 h. The mixture was evaporated under reduced pressure and the residue was triturated in a small amount of acetone. The precipitated crystals were collected by filtration and recrystallized from acetic acid to give the corresponding *products* **6h–l** as pale yellow microcrystalline powders or needles (Table 3).

General Procedure for the Preparation of 3,7,10-*Triaryl*-*pyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,8(1H,3H,7H,10H)-*tetra*-*ones* **6m–p**.—A mixture of 6-arylamino-3-phenyluracils **9m–p** (3 mmol) and 6-chloro-5-formyl-3-phenyluracil **12b** (752 mg, 3 mmol) in DMF (5 cm^3) was refluxed for 5 h. The mixture was evaporated under reduced pressure and the residue was triturated in a small amount of acetone. The precipitated crystals were collected by filtration and recrystallized from ethanol or DMF to give the corresponding *products* **6m–p** as pale yellow microcrystalline powders or needles (Table 3).

General Procedure for the Preparation of 10-*Alkylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,8(1H,3H,7H,10H)-*tetraones* **6q–s**.—A mixture of a 6-alkylaminouracil **9q–s** (4.18 mmol) and 2,4,6-trichloropyrimidine-5-carbaldehyde **13** (884 mg, 4.18 mmol) in acetic acid (20 cm^3) was refluxed for 3 h. The mixture was cooled. The precipitated crystals were collected by filtration and recrystallized from DMF to give the corresponding *products* **6q–s** as pale yellow microcrystalline powders or needles (Table 3).

General Procedure for the Preparation of 10-*Alkyl*-3-*methyl*-8-*phenylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6(3H,7H,10H)-*triones* **7a–h**.—A mixture of a 6-alkylamino-2-phenylpyrimidin-4(3*H*)-one **11a–h** (4.64 mmol) with 6-chloro-5-formyl-3-methyluracil **12a** (875 mg, 4.64 mmol) in acetic acid (20 cm^3) was refluxed for 3 h. The mixture was evaporated under reduced pressure and the residue was diluted with a small amount of ethanol to precipitate crystals, which were collected by filtration

and recrystallized from DMF to give the corresponding *products* **7a–h** as yellow powders or prisms (Table 4).

General Procedure for the Preparation of 10-*Alkyl*-8-*phenylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6(3H,7H,10H)-*triones* **7i–o**.—A mixture of a 6-alkylamino-2-phenylpyrimidin-4(3*H*)-one **11a–g** (4.64 mmol) with 2,4,6-trichloropyrimidine-5-carbaldehyde **13** (981 mg, 4.64 mmol) in acetic acid (20 cm^3) was refluxed for 3 h. The mixture was evaporated under reduced pressure and the residue was diluted with a small amount of ethanol to precipitate crystals, which were collected by filtration and recrystallized from DMF to give the corresponding *products* **7i–o** as yellow powders or prisms (Table 4).

General Procedure for the Preparation of 3,10-*Dialkyl*-8-*phenylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6(3H,7H,10H)-*triones* **7p–r**.—A stirred mixture of compound **7o** (320 mg, 0.572 mmol), the appropriate alkyl bromide (0.858 mmol) and potassium carbonate (102 mg, 0.858 mmol) in HMPA (5 cm^3) was heated at 100 °C for 3 h. The mixture was neutralized with acetic acid. The precipitated yellow crystals were collected by filtration and recrystallized from ethanol to give the corresponding *products* **7p–r** as yellow powders or prisms (Table 4).

General Procedure for the Preparation of 3,7,10-*Trisubstituted* 5,10-*Dihydropyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,8(1H,3H,-7H,9H)-*tetraones* **14a–e**.—A mixture of 3,7,10-trisubstituted pyrido[2,3-*d*:6,5-*d'*]dipyrimidine-2,4,6,8(1H,3H,7H,10H)-tetraones **6a**, **h**, **k**, **m**, **o** (1.2 mmol) and sodium dithionite (783 mg, 4.5 mmol) in 25% aq. ammonia (25 cm^3) was heated at 60 °C for 1 h. The mixture was neutralized with acetic acid. The precipitated crystals were collected by filtration, washed with water, and dried (P_2O_5) *in vacuo* to give the corresponding products **14a–e** as powders (Table 6).

10-*Ethyl*-5,10-*dihydro*-3-*methyl*-8-*phenylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6(1H,3H,7H)-*trione* **15**.—A mixture of 10-ethyl-3-methyl-8-phenylpyrido[2,3-*d*:6,5-*d'*]dipyrimidine-2,4,-6(3*H*,7*H*,10*H*)-trione **7b** (0.3 g, 0.85 mmol) and sodium dithionite (0.9 g, 5.17 mmol) in 25% aq. ammonia (25 cm^3) was heated at 60 °C for 1 h. The mixture was neutralized with acetic acid. The precipitated crystals were collected by filtration, washed with water, and dried (P_2O_5) *in vacuo* to give the product **15** as a yellow microcrystalline powder (299 mg, 99%) which was not recrystallized because of its instability in hot solvents, m.p. > 330 °C; *m/z* 351 (M^+).

1,3,7,10-*Tetramethylpyrido*[2,3-d:6,5-d']*dipyrimidine*-2,4,6,-8(1H,3H,7H,10H)-*tetraone* **16**.—A mixture of 3,7,10-trimethylpyrido[2,3-*d*:6,5-*d'*]dipyrimidine-2,4,6,8(1H,3H,7H,10*H*)-tetraone **6a** (0.25 g, 0.864 mmol), anhydrous potassium carbonate (0.36 g, 2.59 mmol), and methyl iodide (1.23 g, 8.64 mmol) in DMF (20 cm^3) was heated under reflux for 2 h. After cooling, the precipitated potassium carbonate was filtered off and the filtrate was concentrated under reduced pressure to afford *compound* **16**, which was recrystallized from acetic acid to give the pure product as a pale yellow powder (0.21 g, 80%), m.p. > 300 °C (Found: C, 51.5; H, 4.4; N, 23.0. $C_{13}H_{13}N_5O_4$ requires C, 51.5; H, 4.3; N, 23.1%); *m/z* 303 (M^+).

General Procedure for Autorecycling Oxidation of Alcohols—A mixture of a catalyst **6**, **7**, **14**, **15** or **16** (0.04 mmol; 1 mg or 15 mg) with an appropriate alcohol (2 cm^3, 3 cm^3 or 3 g) was stirred in a flask fitted with an air condenser at an appropriate temperature for 25 h or longer. The reaction mixture was analysed by gas chromatography. Afterwards the reaction mixture was diluted with diethyl ether and filtered. The filtrate was treated with a 2 mol dm^{-3} hydrochloric acid solution of 2,4-dinitrophenylhydrazine to give the 2,4-dinitrophenylhydrazone of the corresponding carbonyl compound, which was filtered off, dried (P_2O_5), and weighed. According to ^1H NMR analysis, the crystals filtered off from the above reaction gave a mixture of PPs and the 5,10-dihydro-PPs, and under argon (*i.e.*, without oxygen) the reaction mixture gave primarily the 5,10-dihydro-PPs.

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