

The effect of (natural) polyols on the initial colour of heavy metal- and zinc-free poly(vinyl chloride)

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Abstract

The propensity of (natural) polyols dispersed in heavy metal- and zinc-free PVC sheets to improve the initial colour, e.g. the colour during the first minutes of exposure to high processing temperatures (short-term stability), has been investigated. It is shown using *W(Lab)* values that the initial colour improves upon addition of polyols containing primary hydroxyl groups. The polyols act as HCl scavengers, presumably via an acid-catalysed S_N2 substitution of the primary hydroxyl groups by chloride ions. In contrast, polyols with only secondary or tertiary hydroxyl groups accelerate the thermal degradation of PVC. Notwithstanding, the efficacy of the (natural) polyols containing primary hydroxyl groups will be reduced if the polyol is susceptible to competitive acid-catalysed intramolecular cyclodehydration reactions under the processing conditions. This is substantiated by a comparison of the behaviour of mannitol and 3,4-di-*O*-methyl-D-mannitol. The methylated derivative, which is less prone to undergo intramolecular cyclodehydration, improves the initial colour of heavy metal- and zinc-free PVC sheets more significantly than mannitol itself.

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1. Introduction

It is well documented that for the processing of poly(vinyl chloride) (PVC) the addition of heat-stabilising additives is a prerequisite. This is a consequence of the fact that PVC releases gaseous HCl above 100 °C. This leads to progressive resin discolouration due to the formation of unsaturated structures, degradation of the polymer backbone, and, ultimately, to deterioration of the polymer properties. For many applications a significant initial discolouration of the PVC, which occurs during the first minutes of exposure to the required high processing temperatures, is undesirable. To inhibit discolouration

during long-term heat exposure (natural) polyols are already applied as secondary heat stabilisers in heavy metal-stabilised PVC compounds [1–7]. Unfortunately, however, in these PVC formulations the polyol additives exert a detrimental effect on the initial colour [5,7]. We recently reported that for *heavy metal- and zinc-free* PVC formulations (natural) polyols, especially those containing primary hydroxyl groups, act as HCl scavengers by substitution of the primary hydroxyl moieties by chloride ions [8]. These results prompted us to study in more detail the effect of (natural) polyols on initial colour in the absence of heavy metal- or zinc-containing heat-stabilising additives.

Here, we show that in a *heavy metal- and zinc-free* PVC formulation (natural) polyols markedly improve the initial colour. A firm relationship between the stabilising efficacy of a polyol and the position, number and topology of its hydroxyl

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Table 1
Composition of the rigid, heavy metal- and zinc-free PVC formulation (PVC test compound)

Pre-mix: rigid PVC formulation	Parts per hundred resin (phr ^a)
S-PVC (Marvylan S6806, ex-LVM)	100.00
CaCO ₃ (Omyalite 95T)	2.00
Paraffin wax (drop point 106–112 °C)	0.16
Synthetic paraffin (m.p. 73 °C)	0.46
LDPE wax (drop point 103–110 °C)	0.10

^a phr = parts per hundred parts of resin.

groups is established. To this end, a broad range of polyols of both natural as well as synthetic origins was taken into account.

2. Experimental

2.1. Sheet preparation

All experiments were performed with a standardised pre-mix (so-called “naked” pipe-formulation) kindly supplied by Allstab Chemicals (Table 1).

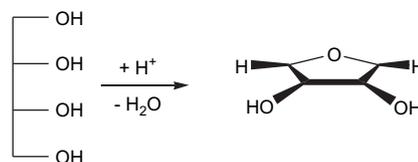
Polyols were added to the pre-mix (120.0 g) and mixed manually. Subsequently, these PVC compounds were processed on a two-roll mill (Schwabenthan Berlin, roll width 22.5 cm, circumference 35 cm, rotation speed front/back 19/23) into rigid sheets by milling at 196 °C for 2 min. The colour of these sheets as determined by averaged *W(Lab)* values is referred to as the initial colour (vide infra).

2.2. Controlled thermal degradation of PVC strips

The PVC sheets were cut into strips (length 20 cm × width 1.8 cm), which were heated in a Mathis oven at a constant temperature of 200 °C according to the DIN 50011 part 2 protocol [9]. The strips were pushed out of the oven at a constant speed (0.5 cm/45 s).

2.3. Colour measurements

The colour of the PVC sheets was measured with a Spectrophen[®] (Dr. Lange) [10] using the three variables *L**, *a** and *b**. The *L** value indicates the lightness of a colour, the *a** value the red-green part and the *b** value the yellow-blue part.



Scheme 1. Intramolecular cyclodehydration of *meso*-erythritol giving 1,4-anhydro-erythritol (erythritan).

A background with a surface with *L**, *a** and *b** values of 92.7, 0.8 and −2.5, respectively, was used as a reference. For each sheet, 10 measurements were performed and the *L**, *a** and *b** values were averaged. The whiteness in the Lab colour system, e.g. the *W(Lab)* value, was calculated using the formula [7]:

$$W(\text{Lab}) = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}.$$

2.4. Congo Red measurements

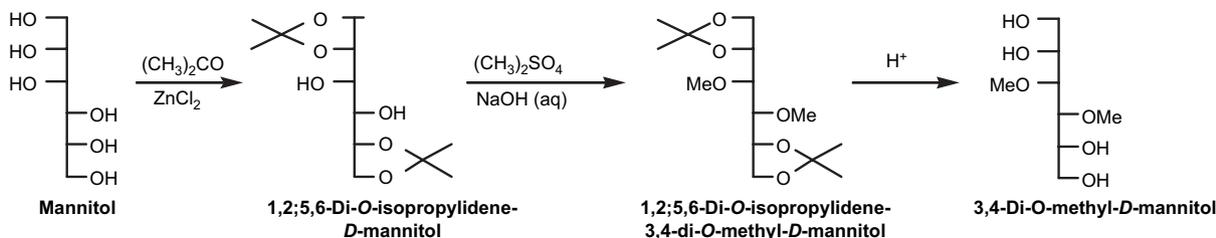
Congo Red (CR) values were obtained by heating ground-processed PVC samples (6.0 g) in a closed test tube, at 200 °C until a strip of CR paper placed at the top of the tube changed colour from blue to red [11]. The time required for the colour change to occur is referred to as the stability time (*t_s*).

2.5. Syntheses

Synthesised polyol derivatives were characterised by a comparison of their ¹³C NMR spectral data, (Bruker DPX-300 NMR spectrometer operating at 75.5 MHz and at ca. 30 °C (solvent DMSO-*d*₆ (Isotec)) with those previously reported (vide infra).

2.5.1. 1,4-Anhydro-erythritol (erythritan)

A round bottom flask (50 ml) containing *meso*-erythritol (0.20 mol, 25 g) and a drop (ca. 0.05 ml) of conc. H₂SO₄ (97%) was heated at 150 °C until complete conversion to 1,4-anhydro-erythritol (erythritan) was achieved (¹³C NMR, Scheme 1). Subsequently the reaction mixture was cooled to room temperature, after which CHCl₃ (100 ml) was added. The organic layer was separated, washed twice with water and subsequently dried using anhydrous magnesium sulphate. After filtration, the filtrate was concentrated under reduced



Scheme 2. Synthesis of 3,4-di-*O*-methyl-*D*-mannitol from mannitol.

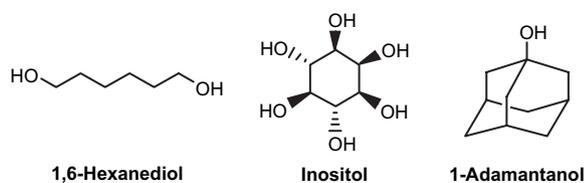


Fig. 1. 1,6-Hexanediol, inositol and 1-adamantanol.

pressure giving pure 1,4-anhydro-erythritol (erythritan; yield 95%, 0.19 mmol, 20 g). ^{13}C NMR (DMSO- d_6): δ 72.4 and 71.2 ppm.

2.5.2. 3,4-Di-O-methyl-D-mannitol

3,4-Di-O-methyl-D-mannitol was prepared in three-steps from mannitol (Scheme 2). First, mannitol (0.41 mol) was converted into 1,2;5,6-di-O-isopropylidene-D-mannitol by treatment with acetone (325 ml) and zinc chloride (70.4 g) at room temperature following the procedure described in Ref. [12] (yield 33%, 0.14 mmol, 35.5 g, m.p. 115–116 °C). ^{13}C NMR (DMSO- d_6): δ 108.2, 74.9, 70.4, 66.7, 26.9 and 25.5 ppm. Next, a DMSO solution (170 ml) of 1,2;5,6-di-O-isopropylidene-3,4-di-O-methyl-D-mannitol (0.13 mol) was methylated with dimethylsulphate (35 ml) in an aqueous NaOH solution (28 g NaOH in 28 ml H₂O) using the procedure described in Ref. [13] (yield 94%, 0.12 mmol, 36.5 g). ^{13}C NMR (DMSO- d_6): δ 107.6, 81.2, 75.5, 65.8, 60.0, 26.2 and 25.0 ppm. Finally, 3,4-di-O-methyl-D-mannitol was obtained by treatment of 1,2;5,6-di-O-isopropylidene-3,4-di-O-methyl-D-mannitol (0.12 mol) with water (100 ml) and acetic acid (200 ml) for 30 min at reflux temperature as described in Ref. [13] (yield 81%, 9.7 mmol, 20.6 g). ^{13}C NMR (DMSO- d_6): δ 79.8, 70.7, 63.4 and 59.8 ppm.

3. Results and discussion

3.1. The effect of the type of hydroxyl groups in polyols on the initial colour

PVC sheets containing 1,6-hexanediol (only two primary OH-groups), inositol (only six secondary OH-groups) or 1-adamantanol (only one tertiary OH-group) were used to assess the effect of the different types of hydroxyl groups on the initial colour (Fig. 1). In all cases, polyols were added in such a way that 40 mmol of hydroxyl groups was present in the PVC test compound (see Section 2.1 and Table 2). The results unequivocally show that the initial colour of the sheets containing inositol or 1-adamantanol is inferior to that found for the blank (Fig. 2). In contrast, the initial colour of the

Table 2
1,6-Hexanediol, inositol and 1-adamantanol mixed in PVC test compound

Polyol	m.p. (°C)	mmol	OH-groups (mmol)	phr ^a
1,6-Hexanediol	40–42	20	40	2.0
Inositol	224–225	6.7	40	1.0
1-Adamantanol	>240	40	40	5.1

^a phr = parts per hundred parts of resin.

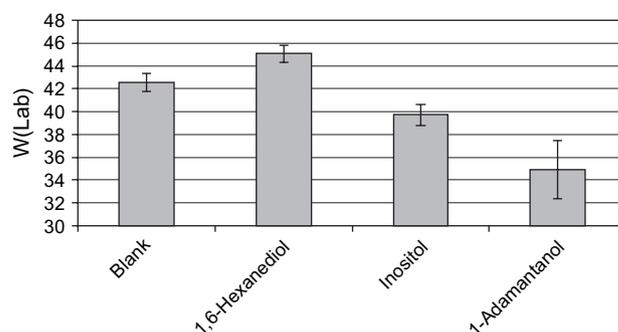


Fig. 2. W(Lab)-values of PVC strips (two-roll mill, 2 min at 196 °C) containing 1,6-hexanediol, inositol or 1-adamantanol.

1,6-hexanediol containing PVC sheet is superior to that of the blank. Hence, the data suggest that only primary hydroxyl groups are effective in improving the initial colour of a heavy metal- and zinc-free PVC test formulation (see also Refs. [2,14]).

Congo Red (CR) values were also determined for the same PVC samples (blank 8.8 min, 1,6-hexanediol 20.3 min, inositol 12.9 min and 1-adamantanol 6.8 min; see also Section 2.4). These results confirm the initial colour W(Lab) data and substantiate that both long-term [8] as well as short-term heat stability appear to depend on the presence and availability of primary hydroxyl groups. Striking in this context is the observation that the tertiary hydroxyl group of 1-adamantanol exerts a distinct destabilising effect.

3.2. A comparison of diols and triols

Next the effects of 1,3-propanediol, 1,3-butanediol, 1,4-butanediol, 1,6-hexanediol, 1,2,6-hexanetriol, glycerol and trimethylolpropane (TMP) were studied. In all but one case, viz. TMP (13.3 mmol), 20 mmol of polyol was mixed with the PVC test compound. Thus, each sheet contained 40 mmol of primary hydroxyl groups. Only in the case of 1,3-butanediol, the sheet contained 20 mmol of primary and 20 mmol of secondary hydroxyl groups (Table 3).

Static heat stability tests of the PVC sheets containing the various polyols showed that the static heat stability time (t_s)

Table 3
Different diols and triols mixed in PVC test compound

Polyol	b.p. (°C)	mmol	Primary OH-groups (mmol)	Secondary OH-groups (mmol)	phr ^a
1,3-Butanediol	203	20	20	20	1.5
1,4-Butanediol	230	20	40	0	1.5
1,6-Hexanediol	250	20	40	0	2.0
1,3-Propanediol	214	20	40	0	1.3
Glycerol	290	20	40	20	1.5
1,2,6-Hexanetriol	168 ^b	20	40	20	2.2
TMP	160 ^c	13.3	40	0	1.5

^a phr = parts per hundred parts of resin.

^b At 6.7 mm Hg.

^c At 2 mm Hg.

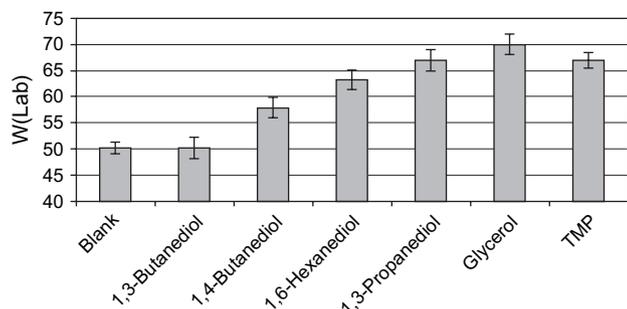


Fig. 3. $W(\text{Lab})$ values of the initial colour of PVC sheets (two-roll mill, 2 min at 196 °C) with 20 mmol of diols and triols (trimethylolpropane (TMP) 13.3 mmol, see also Table 3).

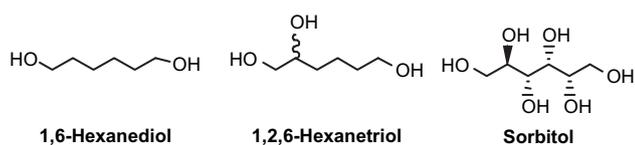


Fig. 4. 1,6-Hexanediol, 1,2,6-hexanetriol and sorbitol.

is nearly identical for all samples (ca. 10 min, cf. Appendix A, Fig. 1A). Furthermore, for nearly all sheets the initial colour ($W(\text{Lab})$ values) improved with respect to that of the blank (Fig. 3). In contrast to 1,3-butanediol, its constitutional isomer 1,4-butanediol significantly improves the initial colour. This difference can only be caused by the change in number of available primary hydroxyl groups. The initial colour is improved even further in the case of 1,6-hexanediol, probably as a result of its higher boiling point, reducing the loss by evaporation during processing. In addition, for α,ω -diols with chain lengths longer than three carbon atoms, acid-catalysed intramolecular cyclodehydration can become a competitive side reaction under the applied reaction conditions. Such a competitive side reaction will effectively reduce the amount of available primary hydroxyl groups [8]. Whereas 1,4-butanediol can be converted into the thermodynamically stable intramolecular cyclodehydration product tetrahydrofuran, for α,ω -diols with chain lengths longer than five carbon atoms this side reaction will be less favourable. Further improvement of the $W(\text{Lab})$ values with respect to that of the blank was obtained with 1,3-propanediol and trimethylolpropane (TMP) (Fig. 3 and cf. Appendix A, Fig. 1A). Primary 1,3-diols show a significant improvement over other α,ω -diols

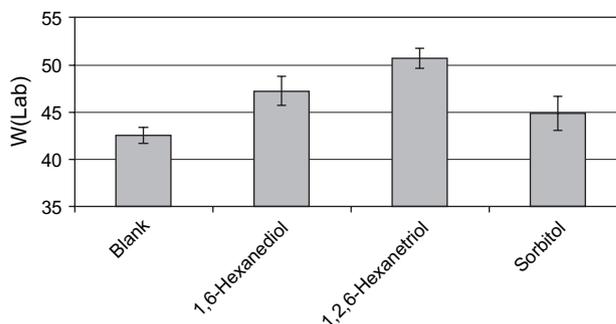


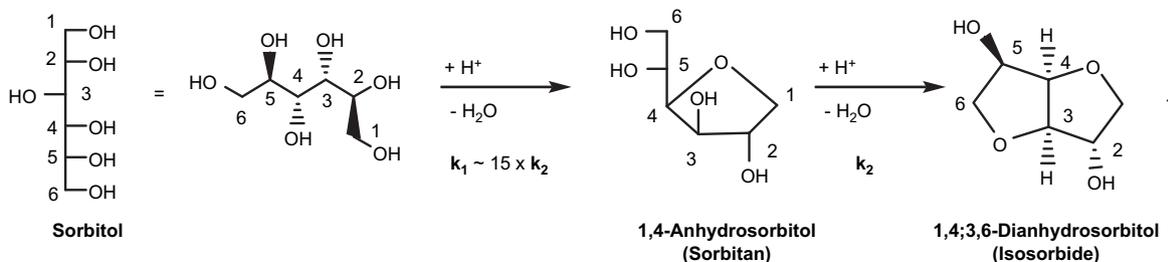
Fig. 5. $W(\text{Lab})$ values of PVC sheets containing 1,6-hexanediol, 1,2,6-hexanetriol or sorbitol.

(compare, for example, the performance of 1,3-propanediol and 1,4-butanediol) probably due to a contribution of neighbouring group effects. This becomes even more pronounced for polyols containing *vicinal* diols, such as found in 1,2,3-propanetriol (glycerol), and by comparison of the behaviour of 1,6-hexanediol, 1,2,6-hexanetriol and sorbitol (Fig. 4). Their $W(\text{Lab})$ values clearly show an improved performance (Fig. 5). It should be noted that the $W(\text{Lab})$ values for the blank and 1,6-hexanediol (Fig. 5) moderately differ from those presented in Fig. 3. These differences presumably reflect changes in processing conditions, such as humidity and temperature of the PVC samples. Strikingly, 1,6-hexanediol outperforms sorbitol, which contains two vicinal diol configurations. As shown previously [8], acid-catalysed intramolecular cyclodehydration of sorbitol (to 1,4-sorbitan, and finally isosorbide, Scheme 3) is a competitive side reaction leading to a considerable reduction of the available primary hydroxyl groups that can act as HCl scavengers (Fig. 5 and cf. Appendix A, Fig. 2A).

3.3. A comparison of a series of alditols

Next, the behaviour of a series of alditols (natural polyols of general composition $\text{HOCH}_2(\text{CHOH})_n\text{CH}_2\text{OH}$ with $n = 1, 2, 3$ or 4 (Fig. 6 and Table 4)) on the initial colour was addressed.

Static heat stability tests (t_s values) revealed that all alditols improve the initial colour ($W(\text{Lab})$ values) relative to that found for the blank (Fig. 7 and cf. Appendix A, Fig. 2A). The improvement in the initial colour increases in the order $n = 4 < 3 < 2 < 1$. All alditols with $n > 1$ are capable of



Scheme 3. Consecutive twofold intramolecular cyclodehydration of sorbitol giving 1,4-anhydrosorbitol (sorbitan) and, finally, 1,4;3,6-dianhydrosorbitol (isosorbide).

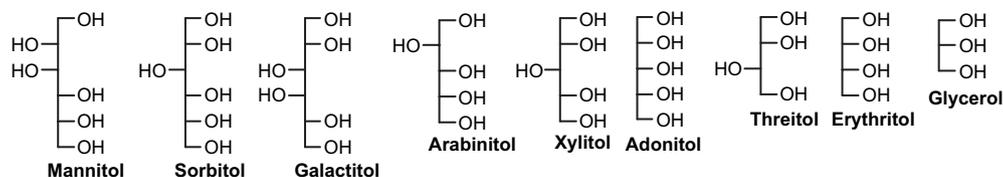


Fig. 6. Various alditols mixed in with the PVC test compound.

yielding acid-catalysed intramolecular cyclodehydration side products that are stable under the applied PVC processing conditions [15–18]. Extraction experiments of processed PVC sheets containing sorbitol have shown that these by-products are indeed formed (Scheme 3; [8]). Hexitols ($n = 4$) like sorbitol can dehydrate intramolecularly to their mono-anhydro, and finally di-anhydro derivatives, e.g. 1,4-anhydrosorbitol (sorbitan) and 1,4;3,6-di-anhydrosorbitol (isosorbide), respectively. Contrary to the hexitols, pentitols ($n = 3$) and tetrیتols ($n = 2$) only yield stable mono-anhydro derivatives under PVC processing conditions. Notwithstanding, in all cases competitive intramolecular cyclodehydration will decrease the number of available primary hydroxyl groups that may participate in HCl scavenging. Note that 1,2,3-propanetriol (glycerol ($n = 1$)) cannot yield a stable intramolecular cyclodehydration product. Consequently, it exerts the highest $W(\text{Lab})$ value.

According to Barker [19], the relative rates for 1,4-anhydro formation in hexitols ($n = 4$) using conc. HCl as catalyst follow the order mannitol < galactitol < sorbitol. A comparable relationship was found for H_2SO_4 -catalysed intramolecular cyclodehydration of mannitol and sorbitol [18]. Since in these studies the consecutive cyclodehydration to the dianhydro derivatives was not taken into account, the order found in Fig. 7 differs from that found previously [19]. The inability of galactitol to yield a stable dianhydro derivative [20] is reflected in its improved performance when compared to sorbitol and mannitol. The pentitols ($n = 3$) tested show improved performance when compared to the hexitols. For example, sorbitol undergoes 1,4-cyclodehydration ca. 10 times faster than xylitol [15,20]. The significant difference in performance between the pentitols and the tetrیتols cannot be explained on the basis of competitive intramolecular cyclodehydration [15], as tetrیتols will give cyclodehydration products

with only inactive secondary hydroxyl groups (see also Ref. [8]).

3.4. A comparison of meso-erythritol and 1,4-anhydro-erythritol (erythritan)

To gain more insight into the apparently anomalous behaviour of the tetrیتols, the effect of meso-erythritol and its intramolecular cyclodehydration product 1,4-anhydro-erythritol (erythritan) on initial colour was investigated. The results show that when increasing amounts of either meso-erythritol or erythritan are added to the heavy metal- and zinc-free PVC test compound a significant effect on initial colour is found (Fig. 8). As expected, these effects appear to be directly related to the absence of primary hydroxyl groups in the case of erythritan.

3.5. A comparison of sorbitol and 1,4-sorbitan

Next, differences in behaviour between sorbitol and its 1,4-anhydro derivative 1,4-sorbitan were studied. To this end either sorbitol or 1,4-sorbitan was added to the PVC test compound in such a way that 40 mmol of primary hydroxyl groups was present prior to processing (Table 5). Since intramolecular cyclodehydration of sorbitol to 1,4-anhydrosorbitol is ca. 15 times faster than the subsequent intramolecular cyclodehydration of 1,4-anhydrosorbitol to 1,4;3,6-dianhydrosorbitol (isosorbide, Scheme 3; [21]), this implies that the amount of primary hydroxyl groups available for HCl scavenging will be lower in the case of sorbitol (even when starting with equimolar amounts of primary hydroxyl groups). This is in line with the observed $W(\text{Lab})$ values (Fig. 9).

Table 4
Different alditols mixed in PVC test compound

Polyol	m.p. (°C)	mmol	Primary OH-groups (mmol)	Secondary OH-groups (mmol)	phr ^a
Mannitol	169	20	40	80	3.0
Sorbitol	95	20	40	80	3.0
Galactitol	190	20	40	80	3.0
Arabinitol	103	20	40	60	2.5
Xylitol	96	20	40	60	2.5
Adonitol	103	20	40	60	2.5
Threitol	88	20	40	40	2.0
meso-Erythritol	122	20	40	40	2.0
Glycerol	18	20	40	20	1.5

^a phr = parts per hundred parts of resin.

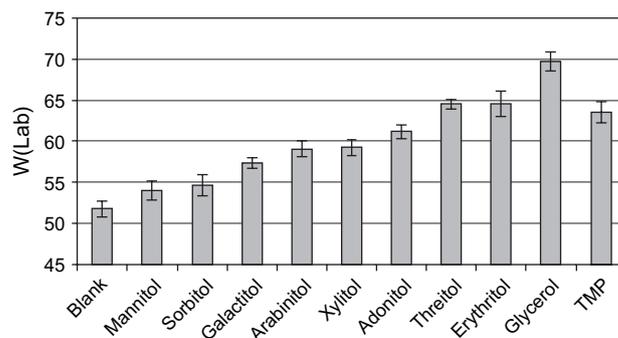


Fig. 7. $W(\text{Lab})$ values of PVC strips (two-roll mill, 2 min at 196 °C) containing alditols.

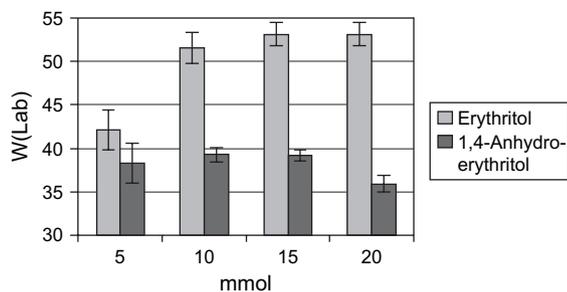


Fig. 8. $W(\text{Lab})$ values of PVC strips (two-roll mill, 2 min at 196 °C) with 5, 10, 15 and 20 mmol of *meso*-erythritol or 1,4-anhydro-erythritol (erythritan).

Table 5
Sorbitol and sorbitan mixed in PVC test compound

Polyol	mmol	Primary OH-groups (mmol)	Secondary OH-groups (mmol)	phr ^a
Sorbitol	20	40	80	3.0
Sorbitan	40	40	120	5.5

^a phr = parts per hundred parts of resin.

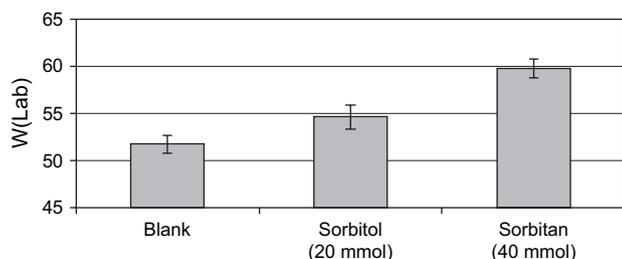
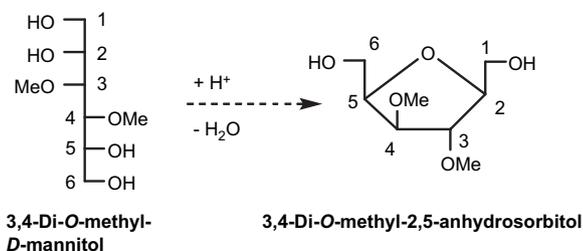


Fig. 9. $W(\text{Lab})$ values of PVC strips (two-roll mill, 2 min at 196 °C) containing either sorbitol or sorbitan (1,4-anhydrosorbitol) (see also Table 5).

3.6. A comparison of mannitol and 3,4-di-*O*-methyl-*D*-mannitol

Since intramolecular cyclodehydration reactions of polyols appear to be a major competitive side reaction that affects the efficacy of polyols to act as HCl scavenger, we were prompted to study the behaviour of polyol derivatives with a reduced propensity for this undesired reaction. To this end, 3,4-di-*O*-methyl-*D*-mannitol was synthesised from mannitol. Note, however, that a complicating factor is another known cyclodehydration mechanism for mannitol that favours the formation of 2,5-sorbitan (3,4-di-*O*-methyl-2,5-anhydrosorbitol, Scheme 4),



Scheme 4. Potential intramolecular, acid-catalysed cyclodehydration of 3,4-di-*O*-methyl-*D*-mannitol [18,19].

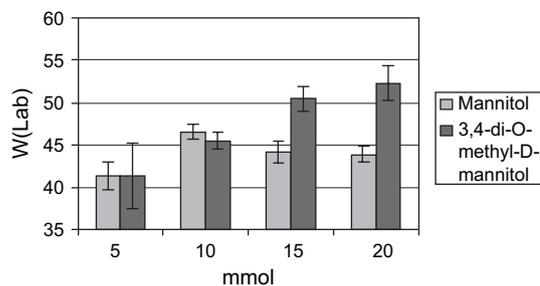


Fig. 10. $W(\text{Lab})$ values of PVC strips (two-roll mill, 2 min at 196 °C) containing various amounts of either mannitol or 3,4-di-*O*-methyl-*D*-mannitol.

which also contains two primary hydroxyl groups [18,19]. Thus, it remains unclear what influence the presence of the methyl groups will have on the propensity to undergo intramolecular cyclodehydration in the case of 3,4-di-*O*-methyl-*D*-mannitol. Notwithstanding, the $W(\text{Lab})$ values reveal that with increasing concentration 3,4-di-*O*-methyl-*D*-mannitol shows an improved performance when compared to that exerted by mannitol itself (Fig. 10).

3.7. A comparison of glycerol and 3-chloro-1,2-propanediol

Thus far, our results have revealed that (natural) polyols stabilise PVC by reacting with HCl under the formation of chlorohydrins [8,12]. Hence, the question arises whether the chlorohydrins are stable under the applied PVC processing conditions. If this is not the case, the chlorohydrin derivatives could, at some point, release HCl, which would contribute to further thermal degradation. Therefore, the effect of the addition of 3-chloro-1,2-propanediol to the PVC test compound was studied and compared to that of glycerol (Table 6).

Unfortunately, 1,3-dichloro-2-propanol could not be tested, because of its low boiling point (174 °C). The $W(\text{Lab})$ results demonstrate that addition of 3-chloro-1,2-propanediol (b.p. 213 °C) improves the initial colour compared to the blank (Fig. 11). Although the effect is small compared to that of glycerol, the increase in the $W(\text{Lab})$ value supports the notion that the chlorohydrins formed in the PVC are stable enough under the applied processing conditions.

4. Conclusions

(Natural) polyols are used in heavy-metal stabilised PVC formulations as *co*-stabilisers, in which they improve the

Table 6
3-Chloro-1,2-propanediol and glycerol mixed in PVC test compound

Polyol	b.p. (°C)	mmol	Primary OH-groups (mmol)	Secondary OH-groups (mmol)	phr ^a
Glycerol	290	20	40	20	1.5
3-Chloro-1,2-propanediol	213	40	40	40	3.7

^a phr = parts per hundred parts of resin.

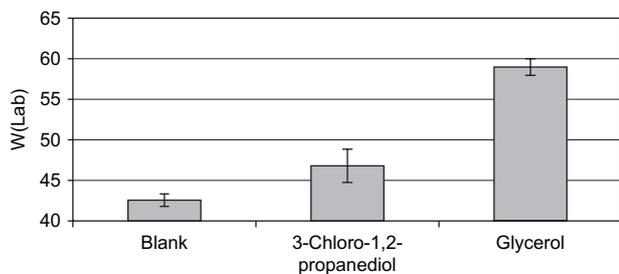


Fig. 11. $W(\text{Lab})$ values of PVC strips (two-roll mill, 2 min at 196 °C) containing either 3-chloro-1,2-propanediol (40 mmol) or glycerol (20 mmol) (see also Table 6).

long-term heat stability by suppressing the autocatalytic degradation by HCl [1–7]. In these heavy metal-stabilised PVC formulations, however, the polyol additive still appears to exert a detrimental effect on the initial colour [5,7]. Since natural polyols may significantly contribute to the development of environmentally benign (next generation) stabiliser systems, we have investigated their effect on the initial colour of a *heavy metal- and zinc-free* PVC formulation. Our results show that in such a PVC formulation polyols with primary hydroxyl groups exert both short-term as well as long-term heat stability (see also Ref. [8]). Especially, polyols with 1,2- or 1,3-diol configurations are found to be highly effective. Notwithstanding, the efficacy of a polyol will be reduced by the occurrence of competitive intramolecular cyclodehydration reaction. This can be circumvented by choosing either a polyol with a reduced tendency towards cyclodehydration (e.g. erythritol), or by selective derivatisation (e.g. 3,4-di-*O*-methyl-D-mannitol). In addition, tests with 3-chloro-1,2-propanediol have shown that the HCl scavenging products, viz. chlorohydrins formed by reaction of primary hydroxyl groups with HCl, will not significantly release HCl under the applied PVC processing conditions. As a consequence, natural polyols thus do not lead to bad early colour in the *heavy metal- and zinc-free* PVC test compound.

Another issue connected with the use of polyol additives, i.e. the occurrence of plate-out and/or dye build up, will be the subject of a forthcoming paper [22].

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Appendix A.

Colour images of *heavy metal- and zinc-free* PVC-polyol strips after controlled thermal treatment in a Mathis oven at 200 °C reflecting static heat stabilities (see Sections 2.1 and 2.2; Figs. 1A and 2A) are shown.



Fig. 1A. Static heat stabilities of PVC strips containing various diols or triols; top, exposed to 200 °C for 0 min, i.e. the initial colour, and bottom, exposed to 200 °C for 30 min. Samples: blank (a), 1,3-butanediol (b), 1,4-butanediol (c), 1,6-hexanediol (d), 1,3-propanediol (e), glycerol (f) and trimethylolpropane TMP (g).



Fig. 2A. Static heat stabilities of PVC strips containing various alditols; top, exposed to 200 °C for 0 min, i.e. the initial colour, and bottom, exposed to 200 °C for 30 min. Samples: blank (a), mannitol (b), sorbitol (c), galactitol (d), arabinitol (e), xylitol (f), adonitol (g), threitol (h) and *meso*-erythritol (i).

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