COMPARATIVE STABILISATION EFFICACY STUDY OF MULTI-FUNCTIONAL STABILISERS IN POLYPROPYLENE DURING MULTI-PASS EXTRUSION AND LONG-TERM HEAT AGEING

B. Johnson[1], N. S. Allen*[2], M. Edge[2], S. Hussain[2], E. Zeynalov[3]

[1]Great Lakes Technology Belgium, Toekomstlaan 13, 2200 Herentals Belgium
[2]School of Natural Sciences, Manchester Metropolitan University, Chester Street, Manchester M15GD, UK
[3] Institute of Chemistry" Public Legal Entity, MSE of the Azerbaijan Republic, Baku, Azerbaijan

* Norman_Allen@sky.com

Received 10.02.2026
Reviewed .16.03.2026
Accepted 20.04.2026

The efficacy of a wide range of multi-functional stabilisers is assessed and compared in the processing and Long-Term Heat Ageing of polypropylene. Melt flow index measurements via multi-pass single screw extrusion were undertaken, coupled with yellowness index for colour inhibition and long-term heat ageing. The outcomes provide novel information for categorising the structural activity of different stabiliser types, enabling effective processing, long-term stability, and colour. Overall, molar hydroxyl activity and sulphur content play a crucial role in melt processability, providing valuable and novel insights into their structure-melt processing interrelationship. Biphenols, aromatic amines, and one hindered amine stabiliser, Tinuvin 123, exhibited the best melt stabilisation, along with the natural antioxidant Vitamin E, displaying similar efficacy. In relation to heat ageing, there was a marked contrast in efficacy, with all the hindered amine light stabilisers exhibiting outstanding performance over the phenolic and aromatic amine stabilisers.

Keywords: *Antioxidants, Stabilisers, multi-pass extrusion, yellowing, polypropylene, Vitamin E*

https://doi.org/10.59849/0005-2531.2026.3.46

Introduction

Antioxidant chemistry plays a vital role in stabilising polymer materials, and none more so than in the range of polyolefins [1-11]. Depending upon the application, the stability requirements vary from simple additives to more complex formulations. Effective processability and end use are often critical, especially where property requirements need to be maintained. Understanding the interrelationship between the structural type of stabiliser and its thermal stabilisation efficacy antioxidants based on phenolic structures were amongst the first to be marketed. Light stabilisers entered the scene with the original idea that if you can block the light on the polymer surface, you will prevent any UV-induced reactions. It is important to note that over the last few decades, much has been learned regarding the multi-functional in polymer materials is crucial to post-use performance and properties. With the advent and developments in polymer materials and the associated degradation problems, there has been a significant growth in the development of stabilisers or inhibitors. In the early years, the focus was on thermal stabilisation, especially for melt processing. Long-term storage of newly manufactured polymers was also a problem [1, 2]. Because many degradation processes are free radical in nature,

behaviour of polymer additives. This includes antioxidants and light stabilisers. There are many grey areas and contradictions in mechanisms, and it has become difficult to compartmentalise additives into specific types. Many antioxidants, for example, have radical scavenging ability but can decompose hydroperoxides [1].

Antioxidant and light stabiliser activity and performance have attracted widespread interest over the last 70 years, with much attention on their mode of action [1,2]. In this regard, research investigations have sought many methodologies to characterise their activity and performance. Stabilisers are often characterised by their ability to perform best at a particular function. This may entail thermal processing, LTHA, colour inhibition, mechanical, hydrolytic, and post-UV stability. In fact, many stabilisers are often marketed based on their best performance to suit a particular application to achieve stabilisation either for thermal or light or both criteria. Some stabilisers can cross both barriers.

With the expansion of many polymer materials into new areas such as medical and food applications, stabilisation has shifted focus to the potential use of natural antioxidants. Such antioxidants would offer less toxicity and, in some cases, enhanced activity. In this respect, there has in recent years been much attention focused on natural antioxidants based on food/fruit/plant flavonoids, polyphenols and vitamins, with extensive research into some of the more successful applicants such as Vitamin E [12-18] and poly(flavonoids) [18].

Although many antioxidants and stabilisers based on phenolics, aromatic amines, phosphites, thioesters and hindered Amines tend to be categorised in terms of their functional use and activity, an experimental comparative study integrating them all has not been carried out. Taking aromatic amines as an example, although it's well-known that they perform extremely well during processing [3,7, 19, 20], their relative efficacy in the context of other multi-functional stabilisers would serve as an extremely valuable reference. This applies likewise to other structural types. To achieve this objective, this study provides a valuable comparative investigation into the thermal stabilisation efficacy of a wide range of stabilisers, totalling 50 in all. They are categorised based on their performances evaluated through extensive 1-5 multi-pass extrusions with Melt flow (MFI) and colour stability (YI) coupled with long-term heat ageing (LTHA) in polypropylene (PP). In addition, to clarify and evaluate the performance of one of the most versatile natural antioxidants, Vitamin E, this extensive study includes the stabilisation efficacy of the compound to ascertain its position in the field of multi-functional stabilisers. For the range of phenolic antioxidants, thermal stabilisation efficacy is related to the functional molar hydroxyl activity to ascertain the validity of this important structural feature. Some valuable interrelationships are clarified with respect to melt versus LTHA and colour (YI), with one important outcome being that high colour formation is linked to exceptional melt stabilisation. In this context, Vitamin E is shown to be comparable to the most effective aromatic amines.

Experimental And Materials

Materials

The PP resin used was an Amoco slurry polypropylene with a nominal melt flow index (MFI) of 12. The MFI of the base PP resin was measured (MFI (230ºC, 2.160 Kg) value 12. The structures and properties of all the materials used in this study are shown in Tables 1 to 5, inclusive of MFI @ pass 5 and LTHA data. The stabilisers are widely available from many other manufacturers around the world. Songwon, BASF, Clariant, SI Group and Adeka Corporation are currently operational.

The MFI and the Yellowness Index of the different compounds were determined at 250ppm. The addition of an acid scavenger is necessary. It neutralises the acid catalyst residues remaining in polymers after the polymerisation process. The calcium stearate used in this study is Faci DW at 500 ppm. The

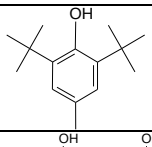
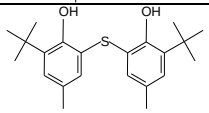
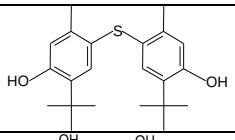
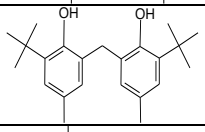
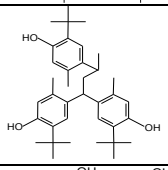
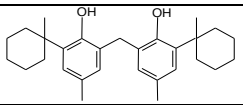
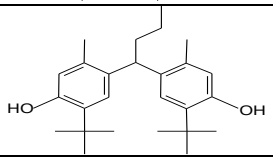
following antioxidants were tested at concentrations varying from 125 to 1000 ppm in PP: Anox 20, Anox PP-18, and Anox IC-14. Lowinox 1790, Lowinox CA-22, BHT and Fiberstab 042. All these formulations contain, in addition, 500 ppm of calcium stearate.

Processing and LTHA

Multi-pass extrusions were undertaken using a Brabender Plasticorder PLE 200, with Screw 1 over 5 extrusion passes. The Temperature profile used was 200-225-250-275ºC in air with a Screw speed of 60 rpm, Batch size of 1200 g. Pass 0 was undertaken to mix the antioxidants into the polymer under nitrogen, where the temperature profile was 200-210-220-230 ºC. Injection moulding was undertaken to produce 1mm plaques over the temperature range 210-220-230-230ºC and 2nd pass with 250 grams. Colour measurements were undertaken using a MacBeth Colour Eye 3000-YI according to ASTM E313 on granules using an ID 65 reflection light source. Experimental error was 0.7 units.

LTHA was carried out in a Heraeus air circulating oven set at 135ºC on the 1 mm injection moulded plaques after pass 2. An average of six plaques was tested. Embrittlement: bending the cross corners for 0,5 cm (1x up + 1x down). Under these ageing conditions, an embrittlement time of 42 hrs was obtained. The PP as supplied was unstabilised.

Table 1: Structures and Properties of Mono and Bisphenols with MFI (pass 5) and LTHA Stability data (250ppm) in PP.

Stabiliser	Structure	Molecular Weight	Molar Activity (mol OH/Kg)	MFI Pass 5	LTHA 135 °C
Lowinox BHT Chemtura/SI Group		222	4.5	28	100
Lowinox TBP-6 Chemtura/SI Group		358	5.6	23.6	116
Lowinox TBM-6 Chemtura/SI Group		358	5.6	22.2	116
Lowinox 22M46 Chemtura/SI Group		341	5.9	19.7	116
Lowinox CA22 Chemtura/SI Group		545	5.5	24.4	99
Lowinox WSP Chemtura/SI Group		421	4.8	21.5	151
Lowinox 44B25 Chemtura/SI Group		383	5.2	25	66

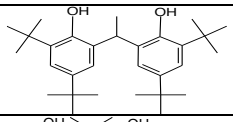
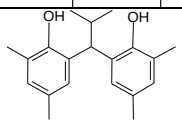
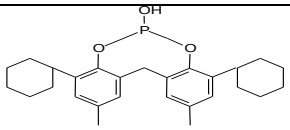
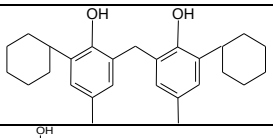
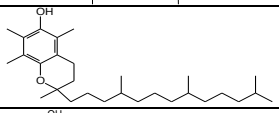
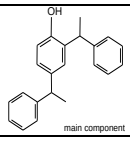
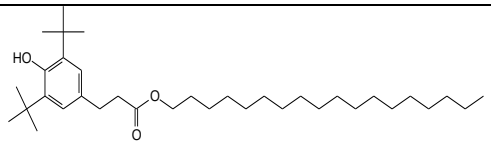
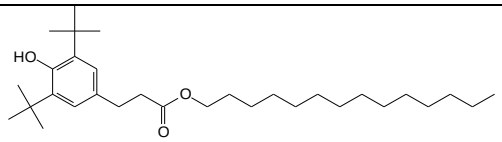
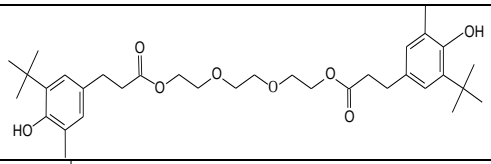
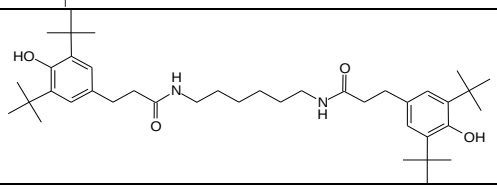
Anox 29 Chemtura/SI Group		439	4.6	29.8	129
Lowinox 22IB46 Chemtura/SI Group		298	6.7	18.2	131
Lowinox CKP Chemtura/SI Group		439	4.6	29.8	129
Lowinox ZKF Chemtura/SI Group		393	5.1	20.4	135
Vitamin E Merck		431	2.3	17	131
Anox G2 Chemtura/SI Group		302	3.3	27.8	105

Table 2(a): Structures and Properties of Hydroxyphenylpropionates with MFI (pass 5) and LTHA Stability data (250ppm) in PP.

Stabiliser	**Structure**	**Molecular Weight**	**Molar Activity (mol OH/Kg)**	**MFI Pass 5**	**LTHA 135 °C**
Anox PP18 Chemtura/SI Group		531	1.9	31.9	176
Anox BF Chemtura/SI Group		475	2.1	34	148
Lowinox GP45 Chemtura/SI Group		587	3.4	26.6	223
Lowinox HD98 Chemtura/SI Group		637	3.1	35.7	149

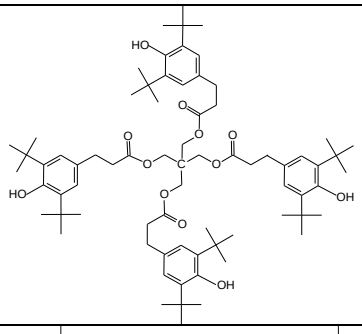
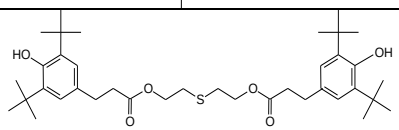
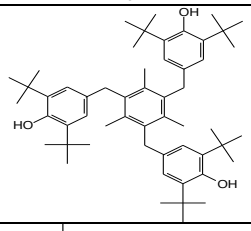
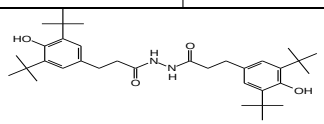
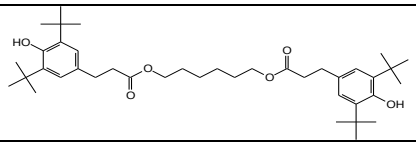
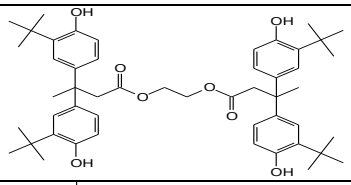
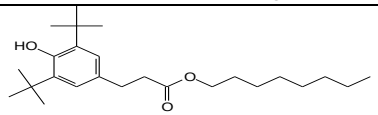
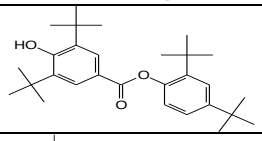
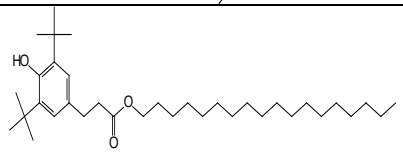
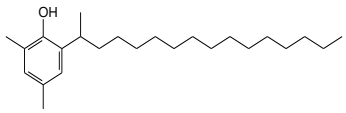
Anox 20 Chemtura/SI Group		1178	3.4	31.4	260
Anox 70 Chemtura/SI Group		642	3.1	26.7	178
Anox 330 Chemtura/SI Group		775	3.9	32.8	248
Lowinox MD1024 Chemtura/SI Group		553	3.6	35.5	219
Irganox 259 SI Group		639	3.1	33.3	226

Table : Structures and Properties of Hydroxyphenylpropionates with MFI (pass 5) and LTHA Stability data (250ppm) in PP.

Hostanox 03 Clariant		794	5.0	34.4	131
Irganox 1135 SI Group		390	2.6	32.7	131
UV Check AM-340 Ferro		438	2.3	44.2	100
Irganox 1141 SI Group	 80%  20%		2.9	27	144

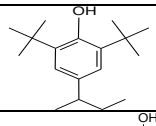
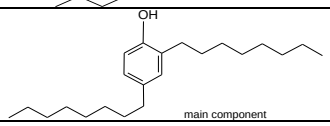
Isonox 132 SI Group		263	3.8	30.5	129
Anox T Chemtura/SI Group		302	3.3	29.3	102

Table 3: Structures and Properties of Multifunctional stabilisers with MFI (pass 5) and LTHA Stability data (250ppm) in PP.

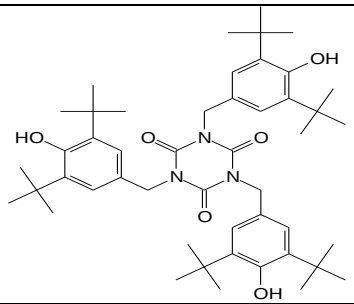
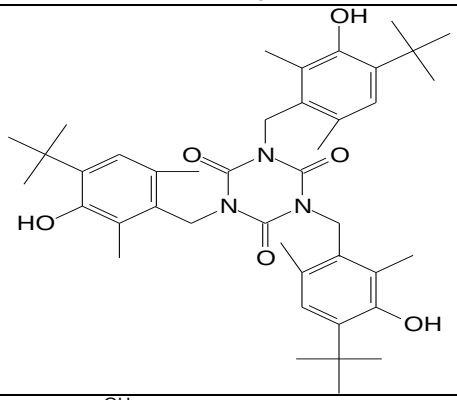
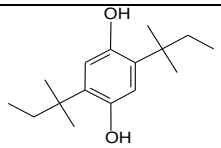
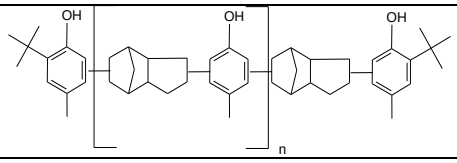
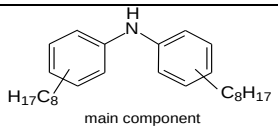
Stabiliser	Structure	Molecular Weight	Molar Activity (mol OH/Kg)	MFI Pass 5	LTHA 135 °C
Anox IC14 Chemtura/SI Group		784	3.8	35.1	78
Lowinox 1790 Chemtura/SI Group		700	4.3	21	150
Lowinox AH25 Chemtura/SI Group		250	8	25.5	116
Lowinox CPL Chemtura/SI Group		700-800		24.4	153

Table 4: Structures and Properties of Aromatic Amine/Phosphites/Thioester stabilisers with MFI (pass 5) and LTHA Stability data (250ppm) in PP.

Stabiliser	Structure	Molecular Weight	MFI Pass 5	LTHA 135 °C
Anox ODS Chemtura/SI Group			26	176

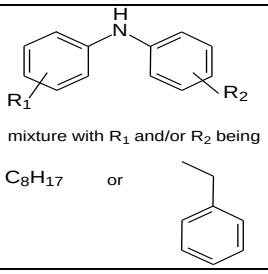
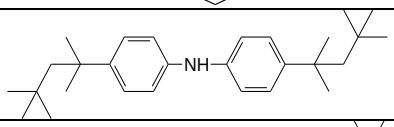
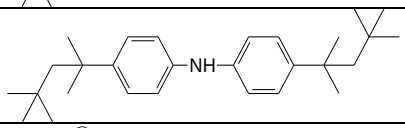
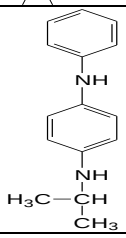
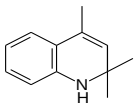
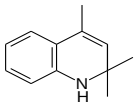
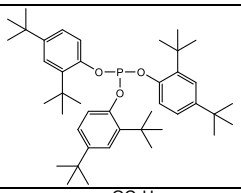
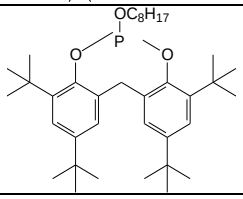
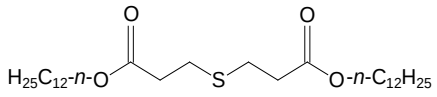
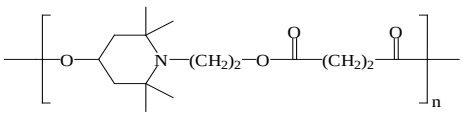
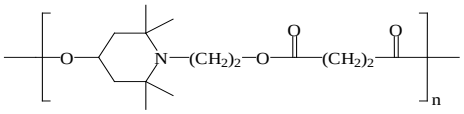
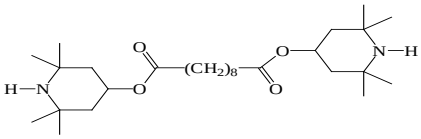
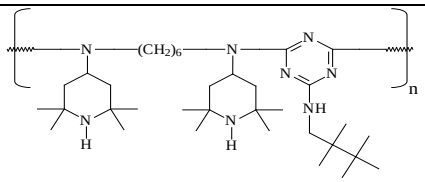
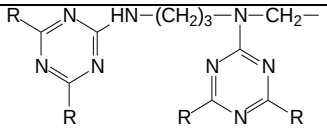
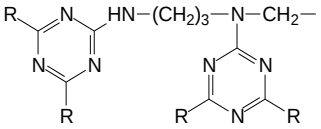
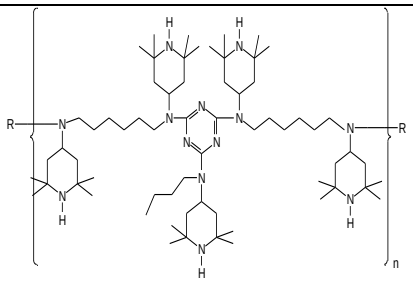
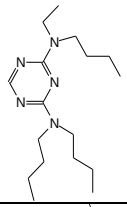
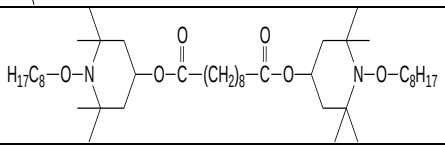
Anox ODL Chemtura/SI Group			27.1	141
N,N-Diphenyl-p-phenylenediamine Merck		260	16.2	158
Irganox 5057 SI Group		281	25.8	143
Vulkanox 4010 Bayer		226	15.8	124
Anox HB Chemtura/SI Group		173	42.6	301
Anox HPG Chemtura/SI Group		173	40.6	9.4
Alkanox 240 Chemtura/SI Group		646	36.2	98
HP-10 Amfine Chemical Corp.		583	33.6	95
Lowinox DLTDP Chemtura/SI Group		515	46.9	150

Table 5: Structures and Properties of Hindered Amine stabilisers with MFI (pass 5) and LTHA Stability data (250ppm) in PP (Plus Unstabilised PP).

Stabiliser	**Structure**	**Molecular Weight**	**MFI Pass 5**	**LTHA 135 °C**
Fiberstab 042 Ciba-Geigy		538	23.5	84

Lowilite 62 Chemtura/SI Group		2500	46.6	487
Lowilite 77 SI Group		481	45.3	303
Lowilite 94 SI Group		>2500	42.9	734
Chimassorb 119 SI Group	 R= 	1157	51	946
Chimassorb 2020FDL SI Group	 R= 		47	842
Tinuvin 123 SI Group		737	17.5	514
Unstabilised PP			42.5	42

Results And Discussions

Comparative Categorisation of Stabilisers

All 50 stabilisers are categorised throughout Tables 1 to 5. They show the structures and suppliers, and for the phenolics, where possible, the hydroxyl molar activities and molecular weights. Stability data for MFI are listed for the multi-pass stage 5, together with the LTHA undertaken at 135 ºC.

The multi-extrusion MFI data for passes 1 and 5 are illustrated in Figures 1 and 2, respectively. Interestingly, at both the high and low MFI ends of the graph plots the least and most effective stabilisers show little change. The best performing stabiliser is the amine Anox BF after pass 1 and after pass 5, with an

MFI shift from 10 to 34. As might be expected, the two aromatic amines. NPPD and Vulkanox 4010 are the most effective, followed closely by Vitamin E. In fact, these three stabilisers exhibit very little change in MFI over the multi-pass stages. The HALS Tinuvin 123 is also effective with a small decrease in MFI from 15.4 to 17.5 over the mult-extrusion range. A similar behaviour is seen for the hydroxylamine Fiberstab 042, which is recommended for PP fibre spinning [10]. The poorest stabiliser is the amine antioxidant Anox HB after pass 1, which moves down the scale from the hindered amines (HALS). All the HALS except the Tinuvin 123 are the poorest melt processing stabilisers after both stages. In fact, they act as processing sensitisers showing worse behaviour compared with the unstabilised PP resin.

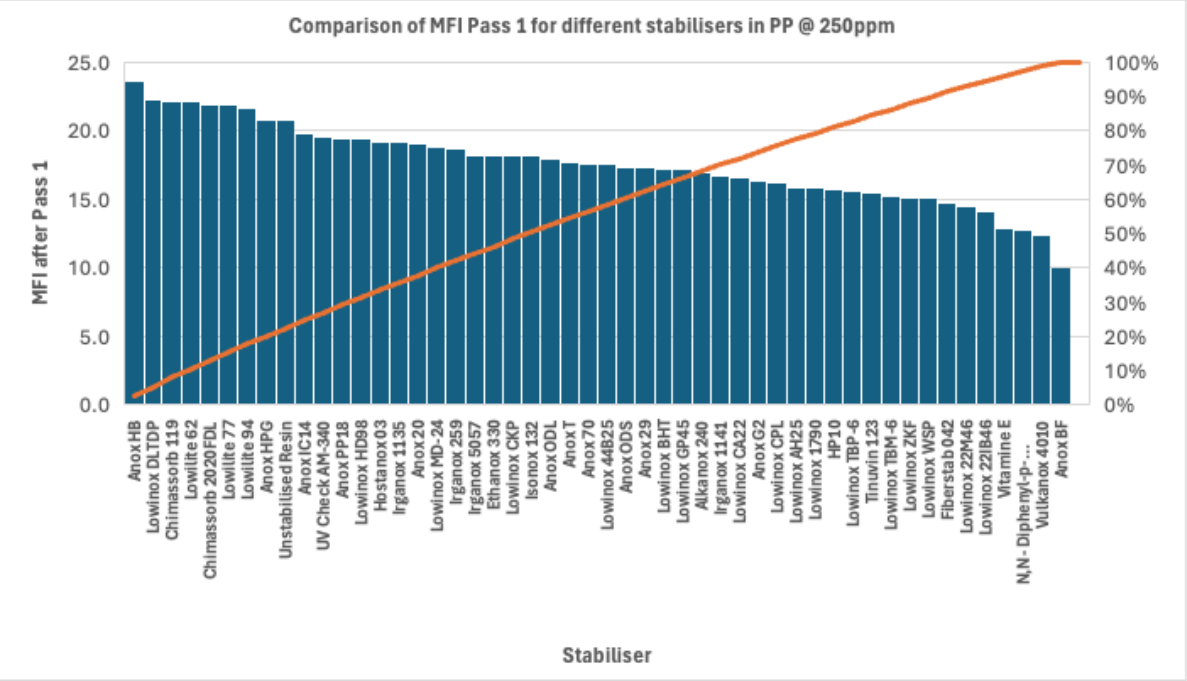


Fig. 1: Comparison of MFI for different stabilisers after multi-pass extrusion 1 in PP @ 250ppm.

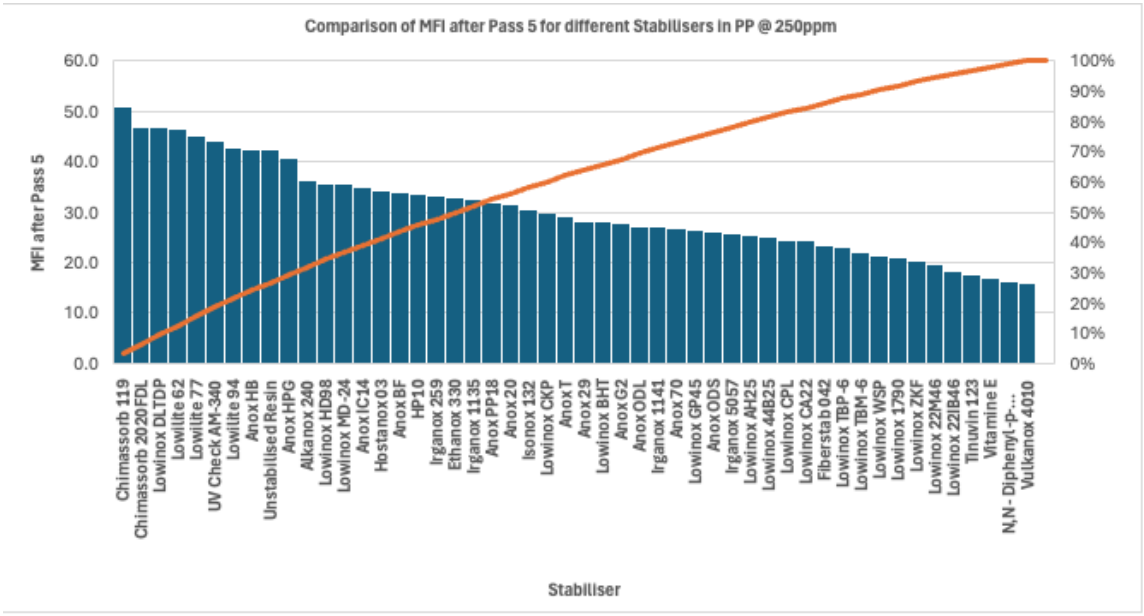


Fig. 2: Comparison of MFI for different stabilisers after multi-pass extrusion 5 in PP @ 250ppm.

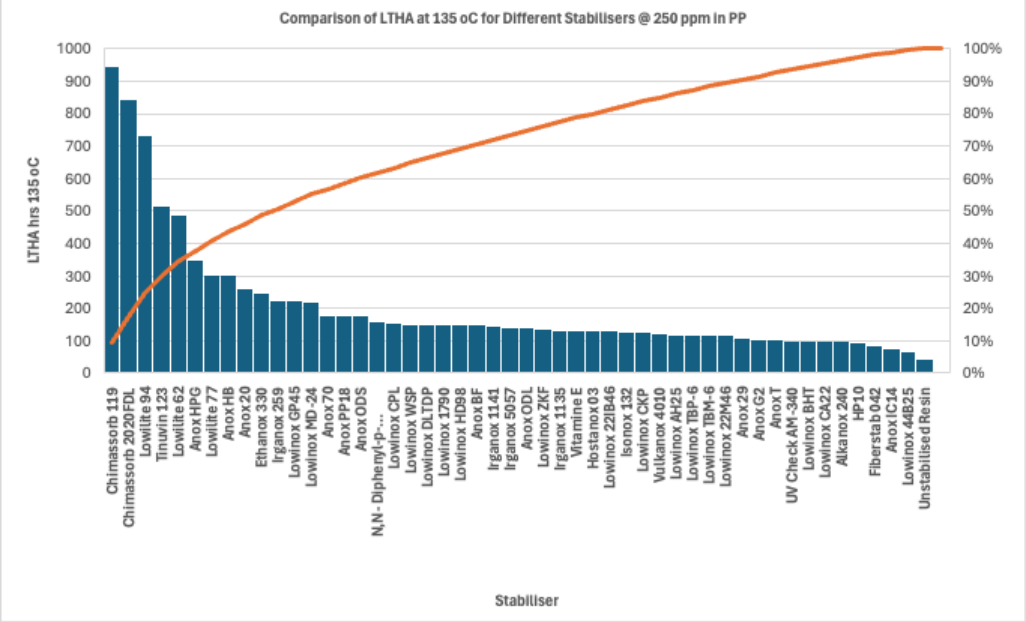


Fig. 3: Comparison of LTHA data for different stabilisers in PP @ 250ppm.

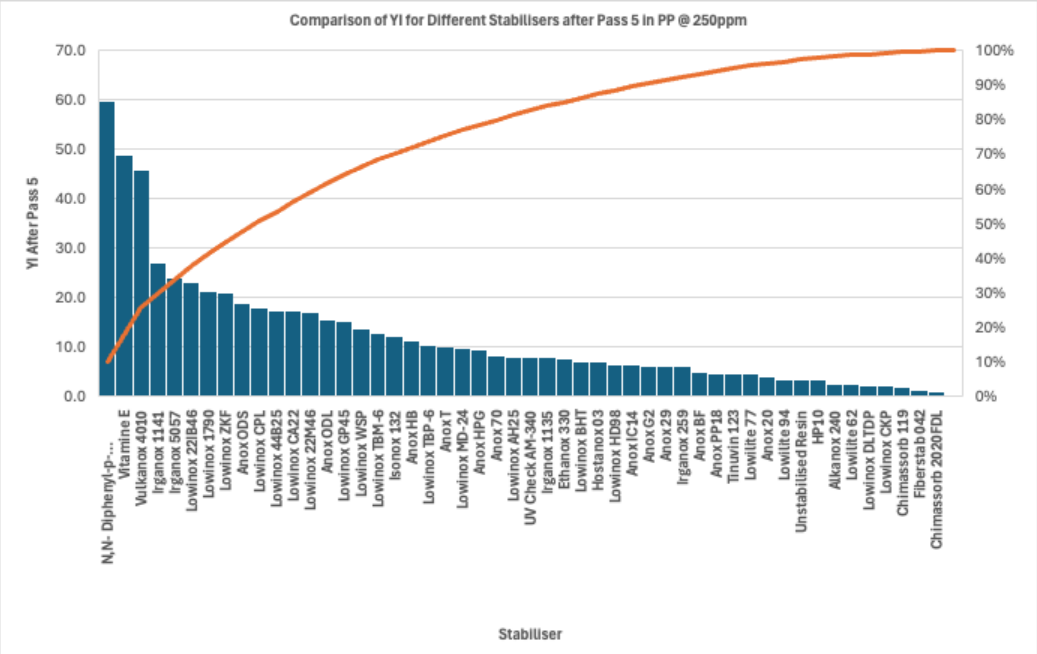


Fig. 4: Comparison of the Colour formation (YI) for different stabilisers in PP after multi-pass stage 5 @ 250ppm.

Regarding the LTHA performances shown in Figure 3, there is a virtual reversal in efficacy. Here, all the HALS, inclusive of Tinuvin 123, exhibit the highest values, while the phosphites and the hydroxylamine are the poorest. The bis and tri-phenol antioxidants Lowinox 44B25 and Anox IC14 were the worst stabilisers for LTHA.

The most significant outcome of the multi-pass extrusions is illustrated by the colour (YI) shown in Figure 4. If Figure 2 for the pass 5 data is overlaid directly with the YI in Figure 4, the stabilisers virtually match in reverse. This is a significant finding, indicating that high MFI protection is associated with high colour (YI). Vitamin E, the HALS, and many of the

phenolic stabilisers exhibit matching trends. This analysis is important since it confirms the multi-functional mechanistic behaviour of many stabilisers, such as those based on phenolics and aromatic amines. Reaction scheme 1 shows a typical cyclic scheme common to many phenolic antioxidants, the key being the formation of quinoid products called stilbenequinones, which are the common cause of polymer discolouration processes [3,6-8]. In this mechanism, there is a reversible transformation from the phenol to the stilbene quinone at each stage, effectively scavenging free radicals. It is essentially an acceptor-donor process and quite effective in stabilisation. The substitution arrangement of the phenolic antioxidant will inevitably control the extent of the quinoid conjugation and hence its stability performance in the melt.

Aromatic amines are also the best chain-breaking donor antioxidants. The aromatic amines react with alkyl peroxy radicals, yielding an aminyl radical (Scheme 2) [20]. Aminyl radicals may also be disproportionate to give the initial amine plus other coupling products. Dimerisation can occur via N-N, C-N and C-C coupling through the mesomeric forms of the aminyl radical, hence their high melt stabilisation performance but also high colour.

Concentration Profiles on MFI and Colour

To determine the extent of the relationship between the MFI stability and colour concentration profiles some of the stabilisers were studied. Examples shown in Figure 5 illustrate concentration profiles for Anox 20, Anox PP-18, Lowinox BHT, Anox IC-14 and Lowinox 1790 for MFI and YI after extrusion pass 5. Again, it can be seen that Lowinox 1790 outperforms Anox IC-14 (Anox 20 and BHT) over the concentration range 1000 ppm. It also shows comparatively high colour formation. Similar trends are observed for Anox PP-18, Lowinox BHT and Anox 20, where overall colour is high for the BHT.

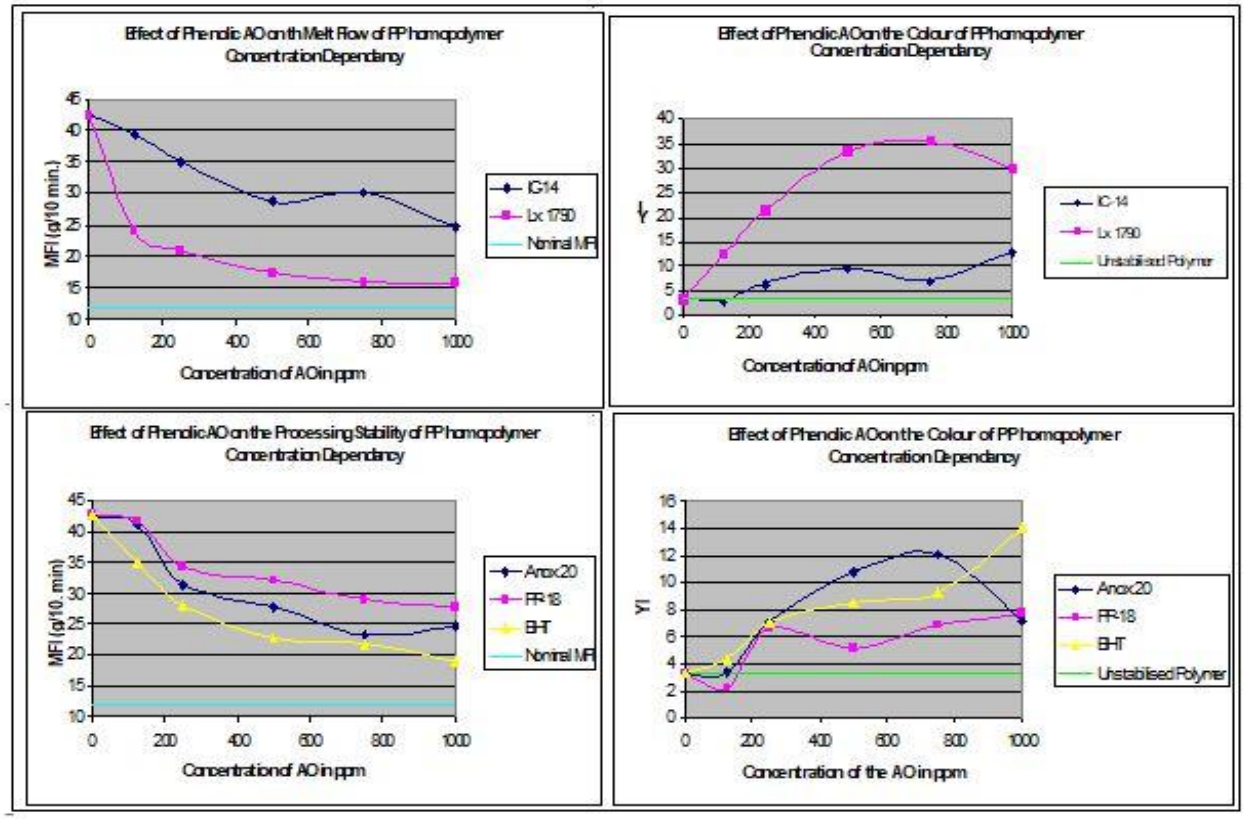
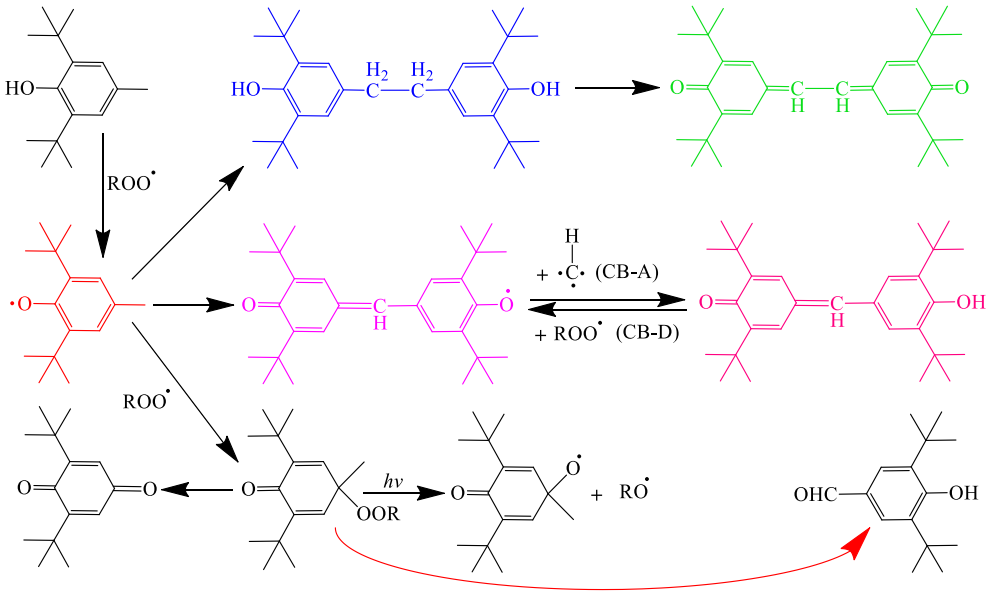
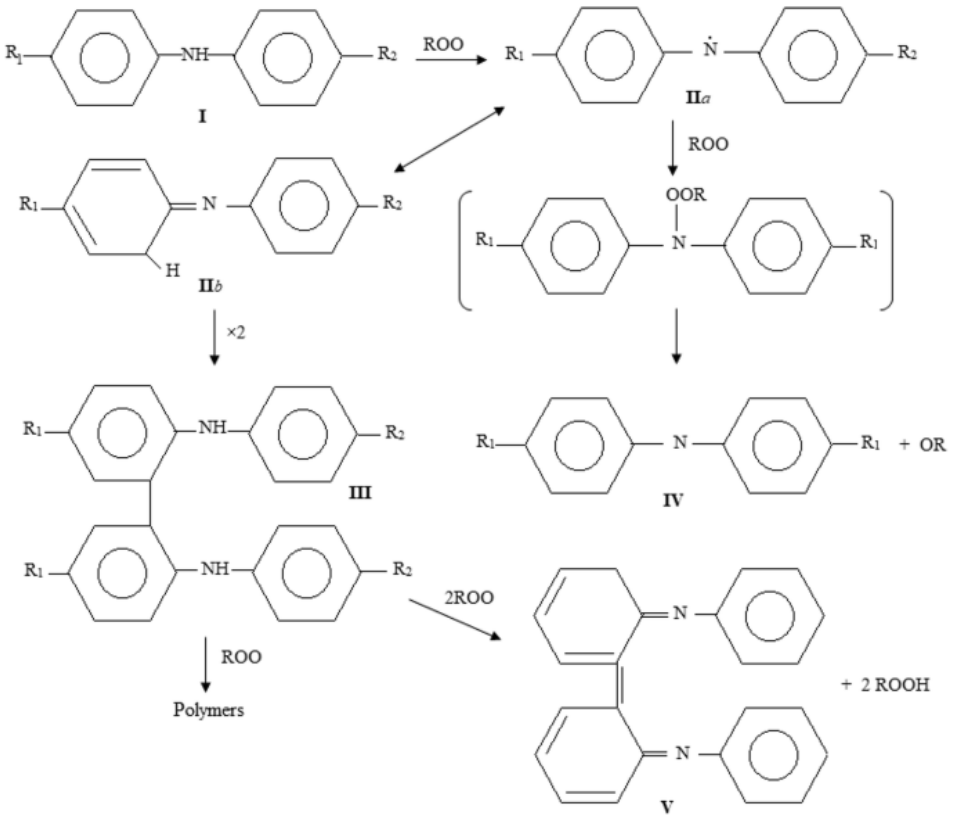


Figure 5: Concentration profiles for Anox 20, Anox PP-18, Lowinox BHT, Anox IC-14 and Lowinox 1790 for MFI and YI after extrusion pass 5.



Scheme 1: Chain-breaking donor-acceptor cyclic mechanism for hindered phenolic antioxidants.

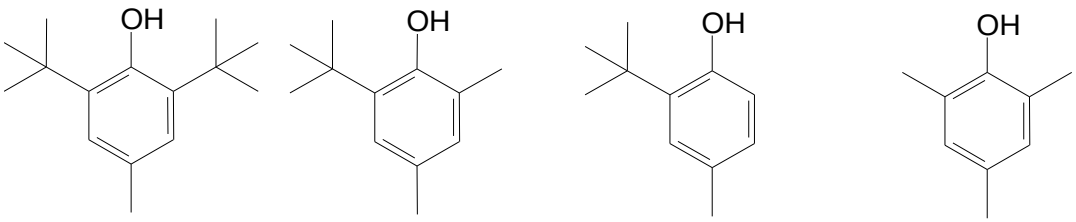


Scheme 2: Complex of transformation of aromatic secondary amine antioxidants.

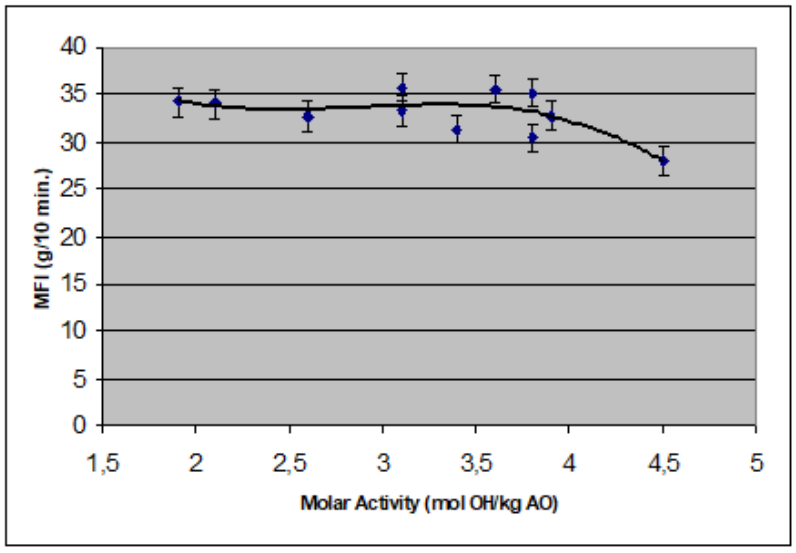
Molar Activity and Efficacy

The hydroxy functionality in phenolic antioxidants is obviously important in terms of their stabilisation efficacy. They are generally considered as active hydrogen atom donors. There has been much discussion in the literature [1-3,5,6,13,20] relating to the molar activity of phenolic antioxidants and their stabilisation efficiency. The ability of free radicals to approach and react with the hydroxyl groups is quite important and determined by the OH hindrance and its strength. The overall structure

of the stabiliser is also important and can interfere with any correlations. The tables 1 and 2 give the molar hydroxyl activities of many of the phenolics.



Scheme 3: Overview of different types of hindrance for phenolic antioxidants.



AO	MA	MFI pass 5
BHT	4,5	28
E330	3,9	32,8
AIC-14	3,8	35,1
I 132	3,8	30,5
MD-24	3,6	35,5
A20	3,4	31,4
HD-98	3,1	35,7
I 259	3,1	33,3
I 1135	2,6	32,7
Anox BF	2,1	34
PP-18	1,9	34,2

Figure 6: Effect of molar activity of 2,6 di-tertiary butyl hindered phenols on the MFI of pass 5, PP homopolymer, all phenols added at 250 ppm

To avoid any structural complications a range of 2,6-ditertiary butyl hindered phenolics was chosen for examination, and a graph is plotted in Figure 6 for MFI after pass 5 at 250 ppm. As can be seen, until a molar activity of 5 all the phenolics give similar performance, with only the BHT showing higher behaviour at 4.5 MA. There was no trend with colour development. However, when looking more specific to phenols hindered with 2, 6-ditertiary butyl groups, but based on the same mono-phenol structure, a clearer trend can be observed (fig. 7). As shown in the plot, the difference between the phenols (Structures given in Tables) is the length of the side chain. A longer side chain will improve the compatibility with the polymer but reduce the molar activity. Here, a linear relationship was found, with the highest molar activity of 4.5 (BHT) giving the best MFI protection and the lowest of 1.9 (PP-18) giving the poorest MFI protection. There are about 6 units of difference.

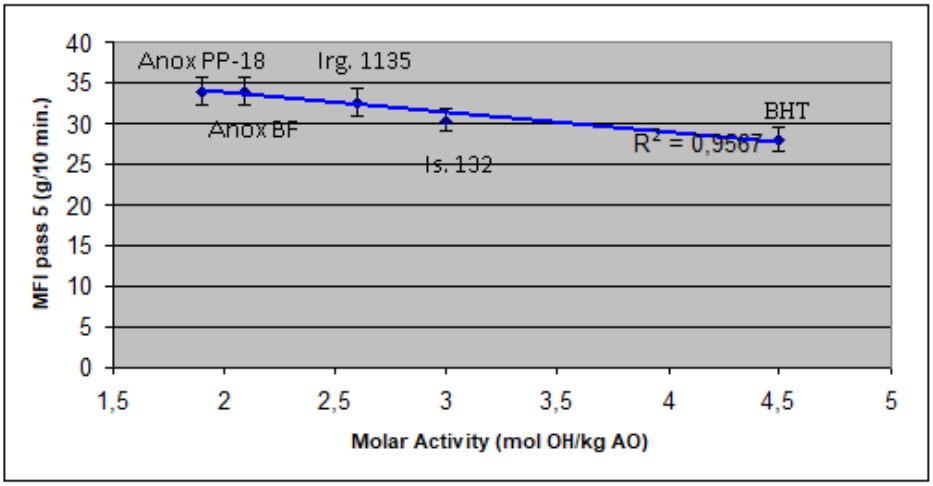


Figure 7: Effect of molar activity of the phenolics on the MFI at pass 5, PP homopolymer, all phenols added at 250 ppm.

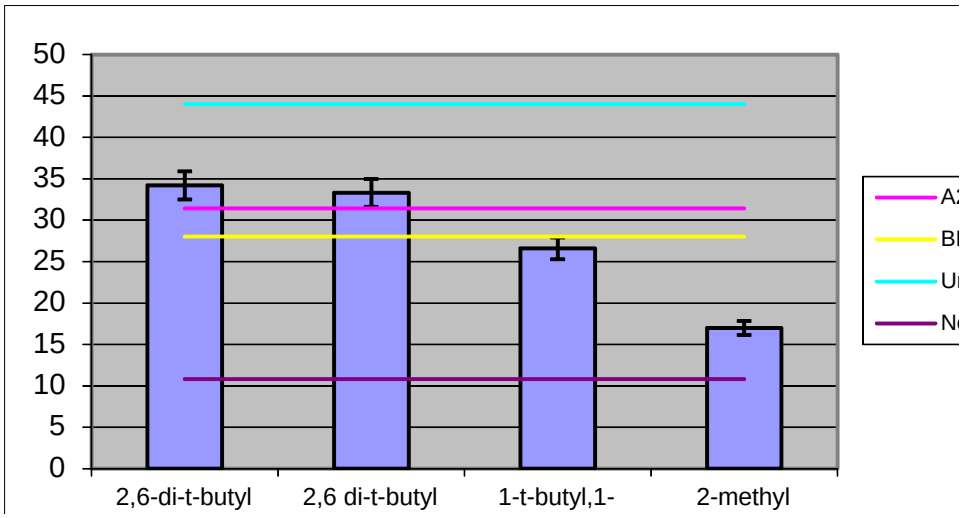


Figure 8: Influence of the hindrance of the functional group of the phenol on the MFI at pass 5, PP homopolymer, all phenols added at 250 ppm, MA: PP-18=1.9, I259=3.1, GP-45=3.4, Vit.E=2.3

If phenols with similar molar activity but with different hindrance are compared, the following effect on the MFI at pass 5, as shown in Figure 8, is observed. A significant drop in MFI at pass 5 could be observed with a lower hindrance. Replacing a t-butyl group with a methyl group result in a significant improvement in the processing stability of the PP. When PP-18 is compared with Vitamin E, a difference of more than 17 units in MFI can be observed. Such an improvement could not be observed when increasing the molar activity. This may lead to the conclusion that low hindered phenols are very efficient processing stabilisers and result in high colour.

Conclusions

The data outcomes in this comparative investigation have drawn together some very interesting and novel relationships between stabiliser structural types and their efficacy in thermal stabilisation by melt processing and LTHA coupled with colour formation. Biphenols, aromatic amines and one HALS, Tinuvin 123, were found to exhibit the best melt stabilisation, along with the natural antioxidant Vitamin E displaying a similar efficacy.

Thioester, polymeric HALS and Tinuvin 770 were poor melt stabilisers throughout the multi-pass stages and worse than the control polymer, showing sensitisation.

In relation to LTHA, there was a marked contrast in efficacy with all the hindered amine light stabilisers exhibiting outstanding performance alongside Tinuvin 123 over the phenolic and aromatic amine stabilisers, with Vitamin E exhibiting only moderate activity but still outperforming many of the phenolics. The phosphites, including the hydroxylamine, exhibit poor LTHA.

There also appeared to be a close relationship between colour (YI) and high melt stability with stabilisers such as the aromatic amines, some phenolics and especially Vitamin E, giving strong colour with the best MFI performance. This could be linked to the fact that stabilisation products such as quinoid and aromatic imine structures also perform as excellent stabilisers through the general acceptor-donor mechanisms. The hindered amines, thioester, hydroxylamine and phosphites gave the best YI inhibition. The stabiliser rankings in Figures 2 and 4 show a mirror image reflection.

A phenol with lower molecular hindrance has a larger effect on the processing stability of PP than a phenol with a higher molar activity. Phenols with lower molecular hindrance impart significant colour to the PP formulation, but this should be partly or completely compensated for by their lower load levels. Concentration studies on the phenolics showed interesting behaviour with Lowinox 1790 outperforming many of the other phenolics during processing, and gave the highest colour production. Transformation products of phenolics during stabilisation are well established as highly effective stabilisers in prolonging the stability of the polymer [21-25].

The experimental thermal stability study here provides a comprehensive comparison of the stabilisation efficacy of many structural antioxidants and stabilisers, which should provide a valuable basis for polymer technologists in the development of additive systems for PP and possibly other polyolefins.

Acknowledgments

The authors thank Great Lakes/Chemtura (Belgium) for partial support of this work for SH and EZ and allowing publication.

Declaration of interest

The authors state that there are no conflicts of interest in this work.

References

1. Allen N.S., Colin X. Properties, chemistry, and mode of action of antioxidants in thermoplastics and rubbers: Recent developments. *J. Vinyl and Additive Technol.* 2022. V.28. P.251-253. https://doi.org/10.1002/vnl.21911.
2. Scott G. (Editor). *Atmospheric Oxidation and Antioxidants*. Oxford: Elsevier, 1993. Vol. III. 376p.
3. Allen N.S. Historical Perspectives and Reflections on the Degradation and Stabilisation of Polymer Materials. *J. Vinyl and Additive Technol*. 2026. V.32. 1-31. doi:10.1002/vnl.70042
4. Pritchard G. (Ed). *Plastics Additives*. London: Chapman and Hall, 1998. 633p.
5. Denisov. E.T. Denisova T.G. *Handbook of Antioxidants*. Boca Raton. FL: CRC Press, 2000.
6. Allen N.S. (Ed). *Degradation and Stabilisation of Polyolefins*. London: Applied Science Publishers, 1983. 384p.
7. Allen N.S., Edge M. Perspectives on Additives for Polymers 1: Aspects of Stabilisation, *J. Vinyl and Additive Technol.* 2020. V.27. P.5-27. https://doi.org/10.1002/vnl.21807
8. Allen N.S., Edge M., Hussian S. Perspectives on Yellowing in the Degradation of Polymer Materials: Inter-relationship of Structure. Mechanisms and Modes of Stabilisation. *Polym. Deg. & Stabil*. 2022. V.201. 109977. doi:10.1016/j.polymdegradstab.2022.109977
9. Gjisman P., Fiorio R. Long-term thermo-oxidative degradation and stabilisation of polypropylene (PP) and the implications for its recyclability. *Polym. Deg.Stabil*. 2023. V.208. 110260. doi:10.1016/j.polymdegradstab.2023.110260
10. Pfaender R. A brief History of Plastic Additives: Part 1: Antioxidants. *Macromol. Mater. Eng.* 2025**.** V.310. №8. 2500039. https://doi.org/10.1002/mame.202500039
11. Fay R.J., King (III) R.E. Degradation and Stabilisation of Polyethylene. M.A. Spalding and A. M. Chatterjee (eds). New York: Wiley, 2017. P.753-769. doi:10.1002/9781119159797.ch25
12. Johnson B., Keck-Antoine K., Allen N.S. et.al. Performance of Vitamin E/phosphite antioxidant stabiliser formulations for polypropylene during multi-pass extrusion processing. *Proc. Petrochem. Oil Refin.* 2025. V.26. P.750-760. doi.org/10.62972/1726-4685.2025.4.1022

13. Alam Md. N., Bristi N.J., Rafiquzzman Md. Review on In-Vivo and In-Vitro Methods Evaluation of Antioxidant Activity. *Saudi Pharmaceutical Journal*. 2013. V.21. P.143-152. doi: 10.1016/j.jsps.2012.05.002
14. Kirschweng B., Tatraaljai D., Foldes E. et. al. Natural Antioxidants as Stabilisers for Polymers. *Polym. Deg. & Stabil*. 2017. V.145. P. 25-40. doi 10.1016/j.polymdegradstab.2017.07.012
15. Takacs K., Nemeth M.A., Renkecz T. et.al. Stabilisation of PE with the natural antioxidant t-resveratrol: Interaction of the primary and the secondary antioxidant. *Polym. Deg. & Stabil.* 2024. V.230. 111046.doi:10.1016/j.polymdegradstab.2024.111046
16. Al-Malaika S. Vitamin E: An Effective Antioxidant for Polymer Stabilisation. *Polym. and Polymer Composites.* **2000**. №8. P.537-542. doi:10.1177/096739112000080853 7
17. Muller D., Voigt W.A., Ghosh J. Vitamin E: A new choice for Polyolefin Stabilisation. *Macromolecular Symposia*. **2001**. V.176. P.17-30. doi.org/10.1002/1521-3900(200112)176
18. Latos-Brozio M., Milczarek K., Masek A. Evaluation of the stabilising effect and ageing time indicator properties of poly(flavonoids) in a cyclic olefin copolymer. *J. Thermal Analysis and Calorimetry*. 2024. V.149. P.9261-9274. doi:10.1007/s10973-024-13431-x
19. Al-Mamary M.A., Moussa Z. Antioxidant Activity: The Presence and Impact of Hydroxyl Groups in Small Molecules of Natural and Synthetic Origin. *Antioxidants-benefits, Sources, Mechanisms of Action.* (Edited by Waisundara, V.Y.) Intertechopen. 2021. P.1-28. doi.org/10.5772/intechopen.95616
20. Breza M., Jelemenska I. Quantum Chemical Studies of the Antioxidant Effectiveness of P-Phenylene Diamines. *J. Vinyl and Additive Technology*. 2022. V. 28. P.352-366. doi:10.1002/vnl.21901
21. Pospisil J. Transformation products of antioxidants: The role of stabilisation mechanisms. *Die Angewandte Makromol. Chemie*. 1988. V.158. P.209-219
22. Zeynalov E.B., Allen N.S., Magerramova M.Y. et al., Evaluation of the antioxidative efficacy of fullerene soot doped by C60/C70 (85/15) for low-density/high-pressure polyethylene nanocomposites. *Azerb. Chem. J.* 2024. V.4. P.18-26. doi.org/10.32737/0005-2531-2024-4-18-26.
23. Johnson B., Keck-Antoine K., Allen N.S., et.al., Perspectives on the Technical, Scientific and Practical Benefits in the Use of Single-Pack Stabiliser Formulations for Polymer Processing. *Azerb. Chem. J.* 2025. V.1. P.25-39 doi.org/10.32737/0005-2531-2025-1-25-39
24. Zeynalov E.B., Agaguseynova M.M., Guseynova E.R. et.al. Electron Affinity and Antioxidative Activity of Aromatic Polycondensed Structures, Fullerenes and Carbon nanotubes. *Azerb. Chem. J.* 2017. V.4. P.73-77.
25. Zeynalov E.B., Naghiyev *Y.M.*. Kinetic Determination of Inhibition Rate Constants for natural Antioxidants in lemon Essential and Black Seed Oils Using a Model Oxidation Assay. *Azerb. Chem. J.* 2016. V.2. P.74-83. doi.org/10.32737/0005-2531-2026-2-74-83

ÇOXKEÇİDLİ EKSTRUZİYA VƏ UZUNMÜDDƏTLİ TERMİKİ YAŞLANMA ZAMANI POLİPROPİLENDƏ ÇOXFUNKSİYALI STABİLİZATORLARIN STABİLİZASİYA EFFEKTİVLİYİNİN MÜQAYİSƏLİ TƏDQİQİ

B. Johnson, N. S. Allen, M. Edge, S. Hussain, E. Zeynalov

Polipropilenin emalı və uzunmüddətli termiki yaşlandırılma proseslərində geniş çeşiddə çoxfunksiyalı stabilizatorların effektivliyi qiymətləndirilmiş və müqayisə edilmişdir. Tədqiqat çərçivəsində çoxkeçidli birvintli ekstruziya üsulu ilə ərinti axıcılıq indeksi ölçülmüş, həmçinin rəng dəyişməsinin qarşısının alınmasını və uzunmüddətli istilik yaşlandırılmasını xarakterizə etmək üçün sarılıq indeksi müəyyən edilmişdir. Əldə olunan nəticələr müxtəlif stabilizator tiplərinin struktur–aktivlik əlaqələrinin təsnifləşdirilməsi üçün yeni məlumatlar təqdim edir və onların emal səmərəliliyi, uzunmüddətli sabitlik və rəngin qorunması baxımından qiymətləndirilməsinə imkan yaradır.

Ümumilikdə, molyar hidroksil aktivliyinin və kükürd tərkibinin ərintinin emal qabiliyyətinə həlledici təsir göstərdiyi müəyyən edilmiş, bununla da stabilizatorların quruluşu ilə ərinti emalı arasındakı qarşılıqlı əlaqəyə dair yeni və dəyərli məlumatlar əldə olunmuşdur. Bifenollar, aromatik aminlər və maneəli amin stabilizatorlarından biri olan Tinuvin 123 ərinti emalının stabilləşdirilməsində ən yüksək effektivlik göstərmiş, təbii antioksidant olan E vitamini isə onlarla müqayisə oluna bilən nəticələr nümayiş etdirmişdir. Termiki yaşlandırılma baxımından isə stabilizatorların effektivliyi arasında əhəmiyyətli fərqlər müşahidə edilmişdir; belə ki, bütün maneəli amin işıq stabilizatorları fenolik və aromatik amin əsaslı stabilizatorlarla müqayisədə üstün performans göstərmişdir.

Açar sözlər: *Antioksidantlar, Stabilizatorlar, çoxkeçidli ekstruziya, saralma, polipropilen, E vitamin*