Shipping and Storing Polymerizable Substances: A styrene incident, complex new legislation and how to do it right

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Abstract

Styrene is one of the most widely used monomers in the chemical industry. It is used in a variety of applications like the production of polystyrene (PS), acrylonitrile-butadiene-styrene (ABS) and styrene-acrylonitrile (SAN). However, it is also well known due to the hazards associated with its undesirable thermal polymerisation reaction.

A significant number of incidents with serious consequences have occurred in the bulk transportation and storage of styrene. By way of illustrating the hazard, the paper reports one such incident on the Stolt Groenland chemical shipping vessel whilst it was alongside at the port of Ulsan, South Korea in September 2019. A large container of styrene monomer began to self-polymerise, self-heat over more than 3 days ultimately resulting in an overpressure release and ignition. Mercifully, there were no casualties but it took 700 firefighters more than 7 hours to bring the blaze under control. The anatomy of the incident highlights the challenge in shipping such materials.

The presence of inhibitor in styrene, as with other monomer and polymerisable substances, during transportation or storage is crucial to ensure the thermal stability of the material and avoid self-polymerisation. The challenge faced by shippers is that the inhibitor is consumed at a complex rate governed by storage temperature and duration. Failure to maintain inhibitor levels can result in self-polymerisation.

Knowing how the inhibitor is consumed and its effect on the “onset temperature” of self-polymerisation enables operators to establish safe systems of work when handling styrene. Experimental data is presented in this paper which demonstrates best practice in assessing self-polymerisation potential. The data probes long duration transportation conditions on inhibited styrene and illustrates how inhibitor depletion affects the “onset temperature” of reaction. Thermal screening tests in conjunction with adiabatic testing are used to obtain experimental data that produce sufficient information to assess the thermal behaviour of inhibited styrene at different stages during a simulated transport storage case.

In recognizing the risks posed by polymerisable substances, the United Nations Transportation of Dangerous Goods Recommendations implemented new criteria, testing protocols and special provisions. These were intended to force producers and shippers to follow a standardised programme to define Self-Accelerating Polymerisation Temperature (SAPT) – a close derivative of the long-standing Self-Accelerating Decomposition Temperature (SADT). However, the nuances of inhibitor depletion in polymerisable substances make the evaluation complex and potentially fraught with possibilities to mis-classify.

This study highlights the protocols and experimental considerations necessary to guarantee the safety handling of styrene during transportation and how to meet the requirements of the special provision 386.

Keywords: Styrene, Special Provision 386, Monomers, UN Classification, Polymerisation reaction, Self-accelerating polymerisation temperature (SAPT).

1 The Challenge of Handling Monomeric Substances

Polymerisation reactions are the most common cause of runaway reaction incidents globally. These reactions typically involve unsaturated organic materials (monomers) which can undergo an exothermic free radical chain reaction often leading to the release of significant energy and associated pressure effects. The huge global use of monomers in the manufacture of polymers magnifies the risk and makes it an imperative to evaluate polymerisable substances during transportation, storage and use. Recent changes to transportation legislation are reviewed in this article, with specific reference to styrene. The new legislation, whilst an improvement, still offers the possibility of inconsistency. Recommendations for consistent storage and transport controls to prevent runaway reactions are contained herein.

The polymerisation reaction of styrene is a rapid exothermic event with a significant release of energy (~500 J/g measured by adiabatic calorimetry). The reaction starts at modest temperatures with an adiabatic temperature rise of approximately 280°C.

Data[1] indicates that 48% of UK reportable incidents due to runaway reaction in the chemical industry from 1962 and 1987 were related to polymerisation reactions (a combination of intentional and unintentional reactions). Significant, serious incidents continue to arise globally with styrene (as reported by Zhao[2]). Table 1 shows a list of incidents resulting from runaway polymerisation of styrene monomer from several sources collated by Zhao.

Date	Location	Injuries	Fatalities
05 July 1994	Kaohsiung, Taiwan	0	1
26 January 1996	Chiayi, Taiwan	1	0
21 January 1998	Kaohsiung, Taiwan	4	0
24 December 1998	Kanagawa, Japan	0	0
27 June 1998	Channahon, IL, US	1	0
23 June 1999	Pasadena, TX, US	21	2
06 October 1999	Chiayi, Taiwan	1	0
27 March 2000	Pasadena, TX, US	71	1
02 April 2003	Addyston, OH, US	0	1
08 April 2004	Jiangsu, China	8	6
30 June 2005	Mesa, AZ, US	0	1
13 September 2019	Kobe, Japan	0	0
28 September 2019	Ulsan, Republic of Korea	17	0
07 May 2020	Visakhapatnam, India	>300	11

Table 1: Land-based (and dock-side) runaway styrene monomer polymerisation accidents since 1990

The stability of styrene (and most other monomeric substances) in transportation and storage is enhanced by the inclusion of small quantities of inhibitor which delays the onset of polymerisation but does not render monomers unreactive in desired polymerisation processes. Several compounds have been identified as having inhibitory effects on polymerisation reactions such as, quinones, nitro compounds, metal salts and thiazines. 4-Tert-butyl catechol (TBC) is the most commonly used polymerisation inhibitor for styrene[3].

The criticality of inhibitors depends on the storage temperature, concentration and oxygen dependency. Inhibitors are consumed in "capping" spontaneously formed monomer free radicals and thus become depleted at a complex rate. Understanding the relationship between temperature, duration and inhibitor concentration is thus critical in avoiding undesired polymerisation. Typically, it is recommended to use a TBC concentration in styrene of 10-15 ppm. Literature suggests that inhibitor levels below 10 ppm will increase the level of polymer formation and below 4 ppm the inhibitor becomes ineffective and the polymerisation is accelerated. The experimental data presented in this paper confirms that styrene containing low inhibitor levels will initiate an exothermic runaway from very low (near ambient) temperature.

Several classes of inhibitor, including TBC, require the presence of oxygen to activate the inhibitor. Typically, it is recommended to store polymerisable substances under air atmospheres to enhance the polymerisation inhibitor efficiency but this conflicts with the need to maintain a non-flammable atmosphere especially with volatile monomers such as styrene. It is recommended to maintain a minimum level of 3-8% v/v of oxygen to prevent the polymer formation when inhibitor is present. Figure 1 shows the optimal oxygen concentration range to balance the inhibitor / flammability risks.

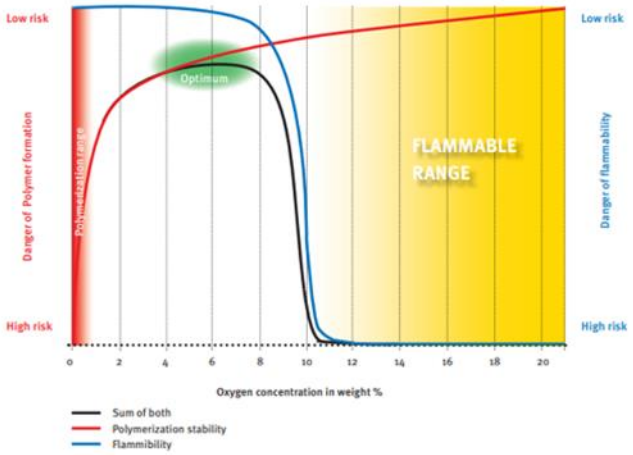

Figure 1: Optimum oxygen concentration to balance flammability and self-polymerisation risks[3]

A study on the inhibition of runaway reactions by inhibitor injection[4] indicated that nitrogen does not cause deactivation of TBC with styrene but this may have been related to the short durations involved in emergency inhibition.

The big challenge with styrene and other monomeric substances is that a definitive "safe" temperature or simple kinetics that can provide a simple "safe" temperature do not exist. Numerous studies reflect the complex relationship between inhibitor concentration and detectable thermal polymerisation onset with many of these defining onset conditions at 40°C or below[5].

For styrene and other common monomeric materials, extensive manufacturer and trade association prescriptive guidance exists on inhibition and control (for example, from the Styrene Producers Association)[3]. The guidance centres on control of both temperature and inhibitor level – through regular monitoring of these parameters – and provides prescriptive action to be taken in the case of deviations. Despite this, incidents continue to occur. Furthermore, for less common and new monomeric substances, the extent of available data can be extremely scarce or non-existent. It is thus the responsibility of those producing and handling such substances to generate sufficient information to reduce risk as far as reasonably practicably (more on this topic in section 5).

2 Stolt Groenland Incident 2019

A perfect example of the risk of polymerisation of styrene in transportation is seen in the 28th September 2019 incident involving a cargo tank containing styrene monomer on board the Cayman Islands registered chemical tanker Stolt Groenland which ruptured due to runaway polymerisation[6]. The catastrophic rupture released a large quantity of vapour to the atmosphere, and it subsequently ignited. Fire-fighting efforts by the emergency services took over six hours and involved more than 700 personnel and 117 units of fire trucks, pumps and fire tugs.

Thirty-seven out of thirty-nine available cargo tanks were in use in the transit, three of which contained styrene (5245 tn styrene in total). In adjacent tanks were cargoes requiring elevated temperature control (6 cargo tanks) maintained in the range 40 – 50°C. Due to the lack of monitoring of temperature and active management of inhibitor concentration in the styrene tanks, the inhibitor depleted, self-polymerisation commenced and caused overpressure of the tank. Although there were mercifully no fatalities, 17 injuries resulted from the fire and explosions – 1 on the vessel, 1 on an adjacent vessel and 15 emergency service workers who were fighting to bring the event under control. Imagery of the first explosion can be seen in Figure 2.

Figure 2: Ignition of styrene vapour after thermal runaway caused overpressurisation of the cargo tank

A similar dangerous styrene monomer polymerisation incident had occurred a couple of weeks earlier on board another Stolt Tankers B.V. ship, Stolt Focus. The heat generated by the polymerisation process was noticed before the critical runaway temperature was reached. The styrene monomer cargoes on board both tankers were loaded at a similar time from the same tank in Houston and were exposed to similar environmental conditions. The incident on board Stolt Focus was not reported to the ship's Flag State or other masters in the Stolt Tankers B.V. fleet.

The MAIB's investigation into the incident showed a number of key failings in management of the consignment, the most significant being that upward temperature trends in the initiating styrene cargo (which were visible up to 6 days before the incident) were not recognised by the crew. As a result of the incident, the MAIB recommended a revision to the (IMO) IBC Code to: "Include in the certificate of protection the actions to be taken in the event of a cargo falling outside of the manufacturer's specified oxygen and temperature limits, and that any actions should be realistic, taking account of the limitations on board ships regarding the monitoring, adding, and mixing of inhibitor during the voyage".

3 Transport Instructions for Styrene

3.1 UN Recommendations prior to the Introduction of SAPT and SP 386

Prior to the (2015) 19th Edition to UN Recommendations on the Transport of Dangerous goods[7] there was little to no mention of *"polymerizing substances"*. The only detail on polymerisation being mentioned in Chapter 2 - Class Provisions. When dealing with chemically unstable substances, they shall not be accepted for carriage "unless the necessary steps have been taken to prevent their dangerous decomposition or polymerisation during carriage.". No special provisions or guidance were outlined on how to test for a polymerising substance or the necessary precautions to prevent a polymerisation reaction from occurring during transport. The closest provision available, at that time, for a polymerising substance came under the heading of Class 4, Division 4.1.*"self-reactive substances"* designed to capture substances which undergo exothermic self-reaction or decomposition at modest temperatures, often requiring temperature-controlled conditions during transit and storage as derived from *"Self-Accelerating Decomposition Temperature"* (SADT) testing.

Polymerisable substances posed a unique risk as they are ordinarily stabilised using chemical inhibitors – meaning that (in stabilised condition) they could "pass" SADT testing protocols but in long duration, warm climate transportation, the inhibitor could be fully consumed, and untoward low temperature polymerisation could occur at much lower temperatures.

3.2 UN Recommendations after Implementation of SAPT and SP386

With the introduction of the 19th edition of the UN Recommendations on the Transport of Dangerous goods (2015)[7], a new physico-chemical hazard, polymerisation, was added to Class 4, Division 4.1. The introduction of *"Self-Accelerating Polymerisation Temperature"* (SAPT[8]), was defined as a criterion for consideration of a self-polymerising substance. If the following criteria were met then the material would be classed as a polymerising substance; if the SAPT ≤75°C (with or without stabilization, as intended for transport) under the conditions and type of receptacle intended for transport and, the heat of reaction be greater than 300 J/g and, does not meet any other criteria for inclusion in Classes 1 – 8.

Edition 19 also introduced Special Provision 386 (SP386) which establishes a guide on how to transport self-polymerising substances. This SP386 highlighted the guidance necessary to follow for temperature control, including the new requirements of SAPT, and guidance on "When chemical stabilisation is employed, the person offering the packaging, IBC or tank for transport shall ensure that the level of stabilisation is sufficient to prevent the substance in the packaging, IBC or tank from dangerous polymerisation at a bulk mean temperature of 50°C, or, in the case of a portable tank, 45°C. Where chemical stabilisation becomes ineffective at lower temperatures within the anticipated duration of transport, temperature control is required". In summary, this provision aimed to ensure that sufficient stabilisation is guaranteed by the person offering the receptacle for transport, through the deployment of chemical inhibition; temperature control; or both (if the inhibitor does not remain effective, at lower temperatures, within the anticipated duration of transport).

As a result, from the 19th edition for transport of dangerous goods, Styrene, which is listed in the IMDG DG as a Class 3 Flammable Liquid, now needs to also follow SP386. However, as Styrene is already a classified material, under Class,3, it must be stored on deck, kept away from sources of heat, and ideally temperature controlled, around 30°C. Due to this classification, it is not necessary to specify an exact SAPT for styrene. For less volatile self-polymerisable substances, SP386 should be fully respected and an exact SAPT should be determined for the specific shipping conditions and duration.

3.3 Shipper Instructions for Styrene

Styrene Monomer is listed under UN NO. 2055; Styrene monomer, STABILIZED. For the precautions necessary to prevent polymerisation during transport, SP386 must be observed. Shippers must ensure that the level of stabilization is sufficient to prevent the substance in the packaging, IBC, or tank from dangerous polymerisation at a bulk mean temperature of 50 °C and of 45 °C for portable tanks. However, when bulk shipment in ships or barges, is of concern, SP386 does not apply. For these shipments, a "Certificate of Protection" is required to ensure that the level of stabilization is sufficient for the conditions and duration of the journey, meeting the requirement under IBC Code 15.13.3[9], and must be provided by the manufacturer/ supplier and be kept onboard during the voyage. This certificate should specify; the name and amount of inhibitor, if the inhibitor is oxygen-dependent, date of inhibitor was added and duration of its effectiveness, any temperature limitation effecting its lifetime, and the actions to be taken if the length of voyage exceeds the effective lifetime of the inhibitor.

During transport it is essential the inhibitor levels are maintained and at no point, during carriage, should the inhibitor levels drop below 10 ppm - to ensure any unwanted polymer formation. The most used inhibitor for styrene is 4- tert-butylcatechol (TBC) an inhibitor which requires oxygen to function properly. This itself presents a conflict from a process safety perspective – flammable liquids are best handled at an oxygen concentration below the limiting oxygen concentration for combustion (LOC; 9% v/v for styrene) but the presence of some oxygen is required to maintain activity of the inhibitor.

Typical manufacturer inhibitor (TBC) levels are usually between 10-15 ppm for styrene, however for high temperature or longer duration shipments, inhibitor levels more than typical manufacturer amounts may be required. In some cases, it is advised to have TBC available onboard (with instructions and crew education on how and when it should be administered). The consignor, or entity responsible for transport should also confirm and determine the quantity of TBC is appropriate for the duration of transport, as the manufacturer may have little to no knowledge of transport details, therefore typical inhibitor levels may not suffice. In cases where temperature differences seen throughout a 24-hour period vary significantly, there is the potential for styrene vapours in the headspace to condense. These condensed vapours contain no TBC, which stays in the liquid phase due to its high boiling point. As a result, necessary precautions should be taken to prevent build-up of polymer on surfaces above the liquid level; pressure-relief valves, for example, are particularly susceptible. When shipping styrene the following data should be checked twice a day, at least 8 hours apart:

- The air and sea water temperatures.
- Tank temperatures, including adjacent spaces (empty or full), the temperature for these adjacent spaces should not be exposed to excessive heat, i.e. temperatures above 35°C.
- The oxygen content and pressure within the tank.
- If possible, inhibitor levels should be tested onboard. As this is typically not possible, when necessary, the ship should be diverted to a port with testing capabilities. Inhibitor (TBC) tends to sink to the bottom over time, therefore it is recommended recirculation, at least twice a week, be performed.

In the event where temperature and oxygen limits are exceeded, temperature and pressure monitoring should be increased for both the styrene tank and adjacent spaces. The source of heat should be identified as soon as possible and if corrective actions are necessary, should be mitigated. Mitigations such as continuous cooling by water spray, should be employed, if the unwanted heat source cannot be removed. Increasing circulation within vessel, can reduce localised heating. Adding more TBC, if available and applicable. Styrene may also be transferred from the impacted vessel into other vessels, if permitted and where possible.

Several areas of confusion remain with SP386 including who is ultimately responsible for its correct adoption for a shipment. The consignor may not be aware of the journey detail – and is hence unable to assure that correct inhibition conditions are specified.

As previously mentioned, this very specific guidance for styrene results from its common use and associated huge scale of manufacture and use. For less well known or newer monomeric substances, the manufacturer has a duty of care to produce similar guidance for the monomer of interest, such that shipping and storage can be safely effected.

4 Experimental Studies on Styrene Aging

To exemplify the complex relationship between inhibitor concentration and temperature, a range of studies were performed as part of this research to provide practical guidance to consignors and shippers – but also to other transporters, handlers, storers and users of monomeric substances in general. Differential Scanning Calorimetry (DSC) and Adiabatic Calorimetry (using Accelerating Rate Calorimetry (ARC)) were used to measure kinetics and thermodynamics of styrene polymerisation throughout the aging of a styrene sample, under air, at 40°C (a not unreasonable average storage temperature during equatorial ship container transit). Inhibitor concentration was measured using gas chromatography / mass spectrometry (GC MS).

4.1 Inhibitor Depletion Rate Study

Styrene monomer (SM) was sourced from four different laboratory chemical suppliers and the first striking finding was the variability of the inhibitor content from the various sources. A Fisher/Acros Organics SM sample with a quoted stabilisation level of 10 – 20 ppm was found to contain around 220 ppm of TBC whilst an Alfa Aesar SM sample with a quoted stabilisation level of 10 – 15 ppm was found to contain around 5 ppm of TBC. The sample used in the study had an initial TBC concentration of 12.6 ppm (usual inhibitor concentration range for TBC in styrene is 10 – 15 ppm) and was stored isothermally at 40°C over the 8 week study period. The SM was sampled at weekly intervals by GC-MS. Table 2 illustrates the decay in active TBC content over the study period.

Week	TBC Concentration (ppm)
0	12.570
1	8.865
2	6.482
3	5.256

4	3.220
5	2.346
6	1.576
7	1.028
8	0.000

Table 2: TBC Depletion rate at 40°C

The rate of inhibitor depletion was not seen to be linear, as was initially expected and as is suggested elsewhere[3]. This may be due to the literature data reflecting a narrow degradation range from 15 to 10 ppm only. Extrapolation of inhibitor depletion rate from higher concentrations may thus be pessimistic / conservative. It was also noted that the measured TBC degradation rate was lower than that indicated in the Styrene Producers Association Guide (see Table 3 below for their data).

Storage Temperature	TBC Depletion	TBC Content		Shelf Life
(°C)	(days per ppm)	Initial (ppm)	Final (ppm)	Assured Days
25	11	15	10	55
30	7	15	10	35
40	1.5	15	10	7
40*	1.9*	12.6*	8.9*	-

* Data from the current study, for comparison.

Table 3: Styrene Producers Association Data on TBC Depletion Rate

4.2 Thermal Stability Studies

The effect of aging and associated inhibitor depletion on styrene stability was examined using adiabatic calorimetry (specifically, using an Accelerating Rate Calorimeter). Samples were tested at weekly intervals. Figure 3 illustrates the raw calorimetric data for the starting material (12.6 ppm TBC) and the 8 week aged material (0 ppm TBC).

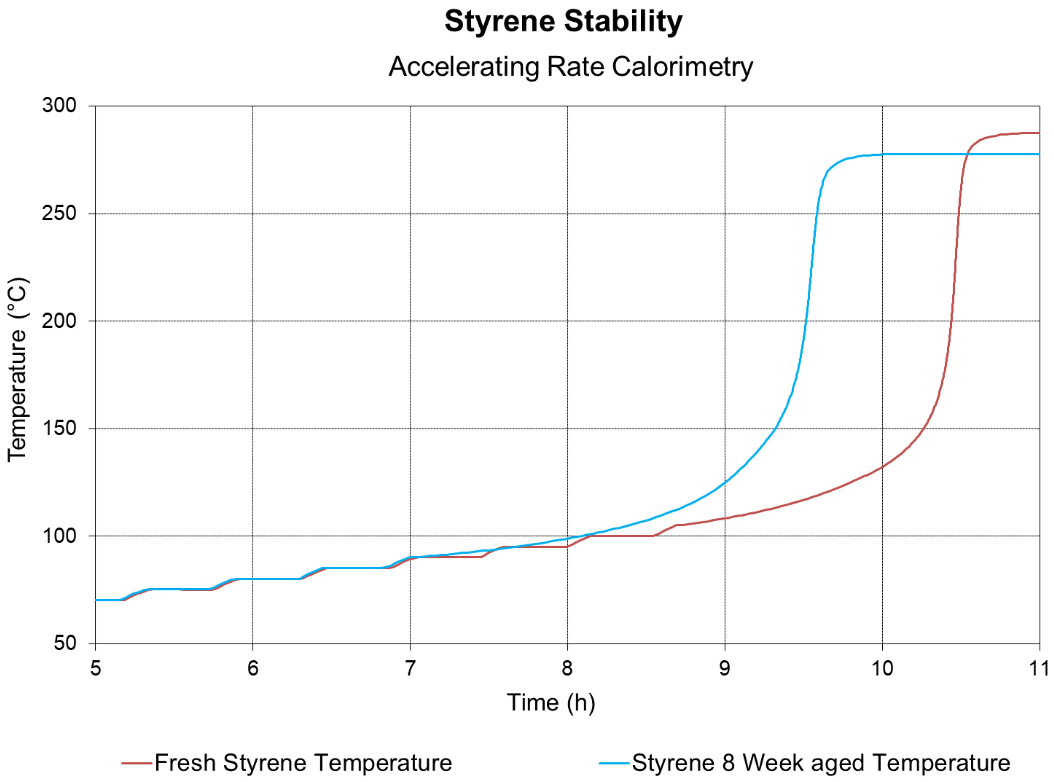

Figure 3: Calorimetric data for fresh and 8 week aged styrene monomer

The data clearly shows a lowered onset of detectable activity (detection threshold set at 0.02 K.min^{-1}) with the aged sample. To provide a more direct comparison of all datasets, the TD_{24} value (the temperature from which maximum rate of runaway is reached over a 24 hour period) has been determined using data corrected for phi factor of the test cell, assuming simple Arrhenius kinetics. Also illustrated is the time to maximum rate from 40°C, 30°C and 25°C. This data is illustrated in Table 4 and Figure 4.

Week	Inhibitor Concentration (ppm)	TD_{24} (°C)	TMR from 40°C (Days)	TMR from 30°C (Days)	TMR from 25°C (Days)
0	12.6	58	3.87	8.83	13.61
1	8.9	54	2.81	6.09	9.15
2	6.5	51	2.21	4.71	7.01
4	3.2	48	1.73	3.54	5.15
5	2.3	48	1.67	3.39	4.92
6	1.6	46	1.45	2.91	4.20
7	1.0	46	1.49	3.00	4.33
8	0	41	1.06	2.05	2.90

Table 4: Comparison of Styrene Stability with Inhibitor Depletion

The TD_{24} values alone illustrate the effect of inhibitor depletion with a 17°C decrease over the 8 week duration of the study. The TMR data also confirm that the duration for polymerisation of styrene becomes close to expected transit durations at very modest temperatures.

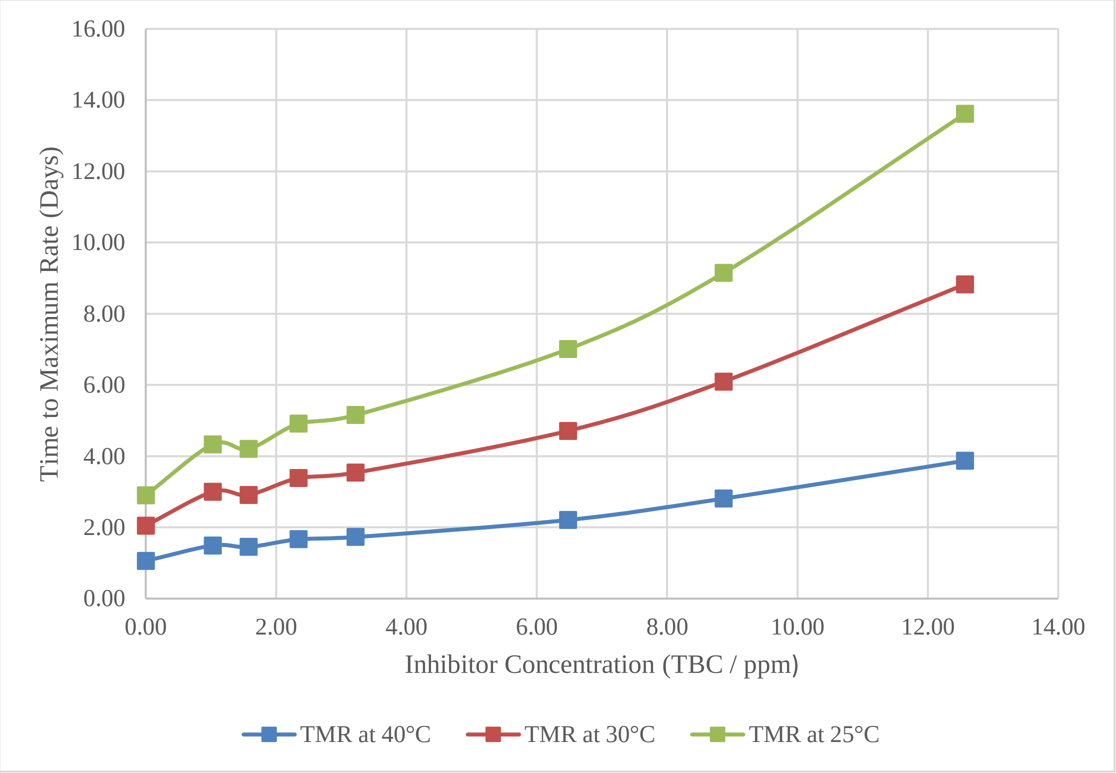

Figure 4: Time to maximum rate with depleting TBC level comparison at different temperatures.

5 Recommendations on Testing Protocols for Self-polymerizable Substances for Transport

Where explicit literature data exists for a specific monomer of interest, it should be followed. Where inhibitor depletion rate data is not fully available, it must be collected by the consignor to provide the shipper with sufficient information to build a monitoring, control and mitigation strategy. The use of inhibitor depletion studies, as exemplified herein, together with thermal analysis using high precision calorimetry, should be deployed to provide explicit guidance on the correlation between storage temperature, inhibitor concentration and runaway kinetics. It may not be economically viable to produce an extensive array of data points, so a specific single consignment analysis (see example in Figure 5) may be a preferred route to safe shipment taking account of maximum foreseeable transport duration and temperature and minimum possible initial inhibitor concentration. If this data is selected very conservatively, it may be retained for lesser consignments / voyages.

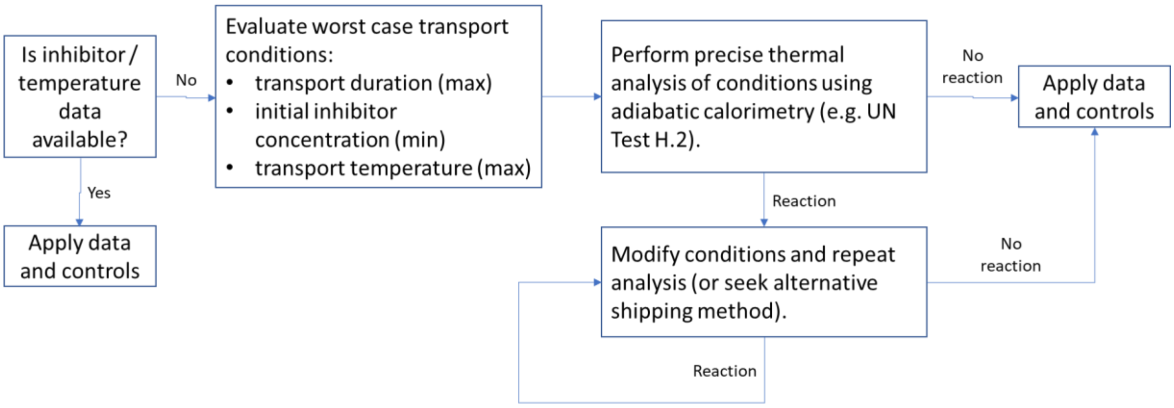

Figure 5: Proposed route for assessing safety of monomer consignments

Whilst prevention is the ideal transport and storage philosophy, knowing the combination of transport / storage duration, maximum temperature and initial inhibitor concentration still requires control measures and mitigation strategies to be in place. A (non-exhaustive) range of control measures and mitigation strategies against the self-polymerisation risk are outlined below:

- Temperature Control
    - Do not store monomers adjacent to any heated container or other heat source.
    - For monomers shipped under temperature control, the assessment of risk should include the scenario of loss of refrigeration – with either prevention (enhanced inhibition) or protection strategies in place.
- Inhibitor and Polymer Analysis
    - Many container ships would not have the facility to perform such analysis but it may be possible to book analysis at planned port stops along the route.
- Headspace oxygen analysis
    - Oxygen is required to activate many inhibitors and hence the oxygen level should be maintained above 3% v/v but below the limiting oxygen concentration for combustion (LOC).

If the temperature starts to rise or other checkpoint deviation occurs, positive temperature control (i.e. forced cooling) or quenching (addition of cool non-reactive, diluent) can be deployed as first line mitigation strategies.

If polymerisation has started and the temperature in the tank or transport is rising it is possible to reduce the polymerisation rate significantly by adding an adequate amount (> 1000 ppm) of free radical scavenger (Short Stop). The short stops must be added when the monomer content is still mobile and not viscous – and must be mixed throughout the monomer. After adding Short Stop the styrene has to be re-processed or discarded. Inhibitors suitable for Short Stop for styrene are Diethylhydroxylamine (radical scavenger), 4-Hydroxy-TEMPO (a stable free radical) and 4-Oxo-TEMPO3 (a stable free radical). Studies on emergency inhibition / short-stopping of styrene have been reported elsewhere[4].

Recommended checkpoints and intervals for styrene are published in the SPA guidance (Table 5) and can be adopted, or adapted, for other monomers.

Checkpoint	Interval		
	≥25°C	>20°C - <25°C	≤20°C
Inhibitor analysis	Daily	2-3 times weekly	Weekly
Polymer analysis	Daily	2-3 times weekly	Weekly
Monomer temperature	Daily	Daily	Daily
Monomer vapour temperature	Daily	Daily	Daily

Table 5: Checkpoint intervals recommended for styrene

All companies that are involved in the transport, storage or handling of styrene should have competent personnel that are trained in the proper use of the relevant distribution facilities, and for the implementation of the relevant safety regulations. As monomers present a unique and complex challenge, the level of education must be assured along the supply chain – including on container ships.

6 Summary and Conclusion

The unique challenge of safely handling and transporting substances liable to (free-radical) self-polymerisation is exemplified in the 2019 Stolt Groenland runaway polymerisation and ensuing severe fire. Whilst for well-known and widely used monomers, data on the correlation between inhibitor concentration, temperature and duration may be readily available, the challenge for manufacturers and consignors of less common and new monomers is to generate applicable and robust data in the most efficient and effective way possible.

The (relatively) recent SAPT criteria within the UN Recommendations on the Transportation of Dangerous Goods more explicitly defines the classification protocol for self-polymerisable substances but some lack of prescription remains which will inevitably lead to some degree of inconsistency in application.

A protocol for single consignment testing and certification is recommended herein which provides a robust and reliable method to improve the safety outcomes associated with the classification process. Inhibitor depletion and thermal stability studies are crucial components in the classification process – along with conservative selection of test parameters (initial inhibitor level, maximum temperature foreseen in transit and maximum foreseen transit duration).

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