Thermal Science and Engineering 2025, 8(4), 11788.
https://doi.org/10.24294/tse11788

Brief Report

Managing heat transfer fluid and system performance in industrial applications

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CITATION

Applications M H. (2025). Brief Commentary. Thermal Science and Engineering. 8(4): 11788. https://doi.org/10.24294/tse11788

ARTICLE INFO

Received: 6 June 2025
Accepted: 29 December 2025
Available online: 4 January 2026

Abstract: Heat transfer fluids (HTFs) are critical in numerous industrial processes (e.g., the chemical industry, oil and gas, and renewable energy), enabling efficient heat exchange and precise temperature control. HTF degradation, primarily due to thermal cracking and oxidation, negatively impacts system performance, reduces fluid lifespan, and increases operational costs associated with correcting resulting issues. Regular monitoring and testing of fluid properties can help mitigate these effects and provide insights into the health of both the fluid and the system. To date, there is no extensive literature published on this topic, and the current narrative review was designed to address this gap. This review outlines the typical operating temperature ranges for industrial heat transfer fluids (i.e., steam, organic, synthetic, and molten salts) and then focuses specifically on organic and synthetic fluids used in industrial applications. It also outlines the mechanisms of fluid degradation and the impact of fluid type and condition. Other topics covered include the importance of fluid sampling and analysis, the parameters used to assess the extent of thermal degradation, and the management strategies that can be considered to help sustain fluid and system health. Operating temperature, system design, and fluid health play a significant role in the extent of thermal degradation, and regular monitoring of fluid properties, such as viscosity, acidity, and flash point, is crucial in detecting changes in condition (both early and ongoing) and providing a basis for decisions and interventions needed to mitigate or even reverse these effects. This includes, for example, selecting the right HTF for the specific application and operating temperature. This article concludes that by understanding the mechanisms of thermal degradation and implementing appropriate management strategies, it is possible to sustain the lifespan of thermal fluids and systems, ensure safe operation, and help minimise operational expenditure.

Keywords: heat transfer fluid; thermal fluid; synthetic fluid; organic fluid; thermal degradation; thermal oxidation

1. Introduction

Heat transfer fluids (HTFs) play a vital role in diverse industrial applications, including chemical processing, oil and gas processing, plastics manufacturing, food production, and solar thermal energy systems [1]. Selecting an appropriate HTF depends on factors such as operating temperature range, thermal stability, viscosity, and cost [2,3]. HTFs are categorised into six primary classes based on their thermophysical properties: (1) gaseous, such as air; (2) aqueous, including water and steam; (3) organic and highly refined organic; (4) synthetic fluids (e.g., Castrol Perfecto HT 5 (red), Globaltherm M, and highly refined organic fluids such as Globaltherm FG); (5) synthetic aromatic fluids (e.g., Dowtherm A, Globaltherm Syntec, Globaltherm Omnitech); (6) molten salts; and (7) liquid metals [3]. They can broadly be classified as mineral or synthetic based on their chemical composition [4,5]. Organic HTFs, which are derived from the fractional distillation of heavy oil, primarily consist of naphthenic and paraffinic hydrocarbons. The structure of their hydrocarbon chains renders them susceptible to thermal cracking, thus limiting their thermal stability to approximately 300 °C (572 °F). However, they are a cost-effective fluid. Synthetic HTFs, including silicone oils and aromatic fluids, provide enhanced thermal stability and a wider operating temperature range, and are relatively more expensive [3,6].

Irrespective of the fluid type, regular monitoring of HTF condition is important, as taking live samples and analysing their physical state is crucial in detecting and mitigating the effects of thermal degradation, along with associated changes that impact the overall system [7]. This paper reviews the physical properties to consider when sampling mineral and synthetic fluids, as well as how to manage fluid health. For instance, it discusses the mechanisms of thermal cracking and oxidation, and the measures used in the laboratory to assess them. It also compares the properties of organic and synthetic HTFs, their propensity for thermal degradation, and how sampling frequency differs by fluid type and condition (e.g., during the flushing of a new system).

To date, there have been a limited number of narrative reviews addressing these points in an industrial setting. The main objectives of this review are to discuss (1) the organic and synthetic fluids used in industrial applications; (2) the mechanisms of fluid degradation and the impact of fluid type on this process; (3) the importance of sampling and analysis, as well as parameters for monitoring thermal degradation; and, (4) management strategies to sustain fluid and system health.

2. Fluid types and properties

HTFs are integral to the operation of heat transfer systems, facilitating efficient heat circulation while maintaining temperature stability [1]. They are essential in operations where precise thermal control is required for operational efficiency and product quality. The typical operating temperatures for steam operations, organic HTFs, synthetic HTFs, and molten salts are depicted in **Table 1**. These fluids offer an effective solution for heating processes that exceed the practical temperature limits of steam-based systems, and, through the utilisation of a heater or furnace, HTF systems can reliably achieve operating temperatures of up to 400 °C (752 °F) depending on the specific fluid being used (see **Table 1**).

Table 1. Typical operating temperature ranges for steam, organic, synthetic, and molten salts.

Fluid type	**HTF specification (manufacturer)**	**Operating range °C (°F)**	**Reference**
Steam	Deionized or distilled water (N/A)	Low-pressure: 100 (212) Medium-pressure: 100 (212) to 180 (356) High-pressure ≥180 (356) Super-heated: 232 (450) or higher	[8,9]
Organic	Globaltherm M (Global Heat Transfer)	−10 to 320 (14 to 608)	[10]
Organic	Mobiltherm 605 (Mobil Oil Corporation)	−12 to 315 (closed system) (10.4 to 599)	[11,12]

Organic	Shell Heat Transfer Oil S; previous name, Shell Thermia B (Shell Oil Company)	−12 to 320 (10.4 to 608)	[13,14]
Organic	Perfecto HT 5, red; previously called Transcal N, red (Castrol)	−10 to 320 (14 to 608)	[15]
Synthetic (Biphenyl ($C_{12}H_{22}$), diphenyl ether ($C_{12}H_{10}O$))	Globaltherm Omnitech (Global Heat Transfer)	15 to 400 (59 to 752)	[16]
Synthetic (Biphenyl ($C_{12}H_{22}$), diphenyl ether ($C_{12}H_{10}O$))	Dowtherm A (Dow Chemical Company)	15 to 400 (59 to 752)	[17]
Synthetic (Hydrogenated terphenyl ($C_{18}H_{22}$))	Therminol VP-1 (Solutia)	12 to 400 (53.6 to 752)	[18,19]
Synthetic (Benzyl toluene ($C_{14}H_{14}$))	Marlotherm SH (Eastman)	−5 to 350 (23 to 662)	[20]
Synthetic (Polydimethyl Siloxane)	Helisol 5A (Wacker)	−5 to 430 (23 to 806)	[21,22]
Synthetic (Blend of benzyl- ($C_{14}H_{14}$) and dibenzyltoluene isomers ($C_{21}H_{22}$))	Jarytherm BT 06 (TotalEnergies Lubricants)	−65 to 290 and 350 under pressure (-85 to 554 and 662)	[23]
Molten salt	Sodium nitrate, $NaNO_3$ (N/A)	310 (590) [a] to 380 (716) [b]	[24]
Molten salt	Sodium nitrite, $NaNO_2$ (N/A)	270 (518) [a] to 320 (608) [b]	[24]
Molten salt	Potassium nitrate, KNO_3 (N/A)	337 (638.6) [a] to 537 (998.6) [b]	[24]
Molten salt	Sodium carbonate, Na_2CO_3 (N/A)	851 (1563.8) [a] to 1600 (2912) [b]	[24]
Molten salt	Potassium carbonate, K_2CO_3 (N/A)	891 (1635.8) [a] to 1310 (2390) [c]	[24]
Molten salt	Lithium carbonate, Li_2CO_3 (N/A)	723 (1333.4) [a] to 1,342 (2447.6) [b]	[24]
Molten salt	Sodium chloride, NaCl (N/A)	801 (1473.8) [a] to 1465 (2669) [b]	[24]
Molten salt	Potassium chloride, KCl (N/A)	770 (1418) [a] to 1420 (2588) [b]	[24]
Molten salt	Magnesium chloride ($MgCl_2$)	714 (1317.2) [a] to 1412 (2573.6) [b]	[24]
Molten salt	Potassium fluoride, KF (N/A)	858 (1576.4) [a] to 1502 (2735.6) [b]	[24]

Notes: [a]: Melting temperature; [b]: Boiling temperature; [c]: Decomposition at this temperature. N/A, not applicable. HTF, heat transfer fluid.

3. Thermal degradation and the Arrhenius equation

Organic and synthetic HTFs' degradation is a complex process that involves various chemical reactions, but thermal cracking and oxidation are the two primary degradation mechanisms [1]. Thermal cracking occurs when the HTF is exposed to temperatures above its maximum operating limit. This causes the hydrocarbon molecules to break down into lower molecular weight compounds ("lower boilers" or "light-ends"), leading to an overall reduction in fluid viscosity [25]. This process also leads to a reduction in flash point temperature, fire point temperature, and autoignition temperature, which can pose safety risks and reduce system efficiency [26]. Excessive thermal cracking, due to severe or prolonged degradation [27], can produce "higher boilers" and result in the formation of larger polymerised molecules that may increase fluid viscosity and even lead to the formation of sludge if they exceed solubility limits [28]. The formation of solid carbon deposits can foul heat transfer surfaces and reduce system efficiency [29].

Oxidation occurs when a hot HTF comes into contact with air. This reaction leads to the formation of organic acids, which can further degrade the fluid and increase its viscosity [30]. As oxidation progresses, it produces high-molecular-weight compounds and insoluble byproducts that contribute to the formation of sludge. In severe circumstances, oxidation can result in sludge formation, heater buildup, and reduced heat transfer efficiency [31]. In such cases, oxidation can lead to an increase in a fluid's total acid number (TAN), particularly in the presence of moisture [32], which can corrode system components and shorten the fluid's lifespan.

Understanding thermal degradation is important when trying to optimise fluid and system performance. The Arrhenius equation can be used to understand the fundamentals of the relationship between fluid temperature and reaction rate, and thus a fluid's degradation - including how this is influenced by fluid composition [33]. The equation states that the rate constant of a chemical reaction increases exponentially with increasing temperature. It is expressed mathematically as: $k = A \text{ x } \exp(-Ea/RT)$, where k is the rate constant of the reaction, A is the pre-exponential factor (frequency of collisions with correct orientation), Ea is the activation energy (minimum energy required for reaction), R is the gas constant, and T is the absolute temperature (in Kelvin).

Figure 1 compares the degradation rate of two hypothetical fluids – one organic and the other synthetic. The x-axis represents the inverse of temperature (1/T) (i.e., a decreasing value represents a rising temperature) and the y-axis represents the natural logarithm of the degradation rate (ln(k)) (i.e., an increasing value represents a higher rate of degradation).

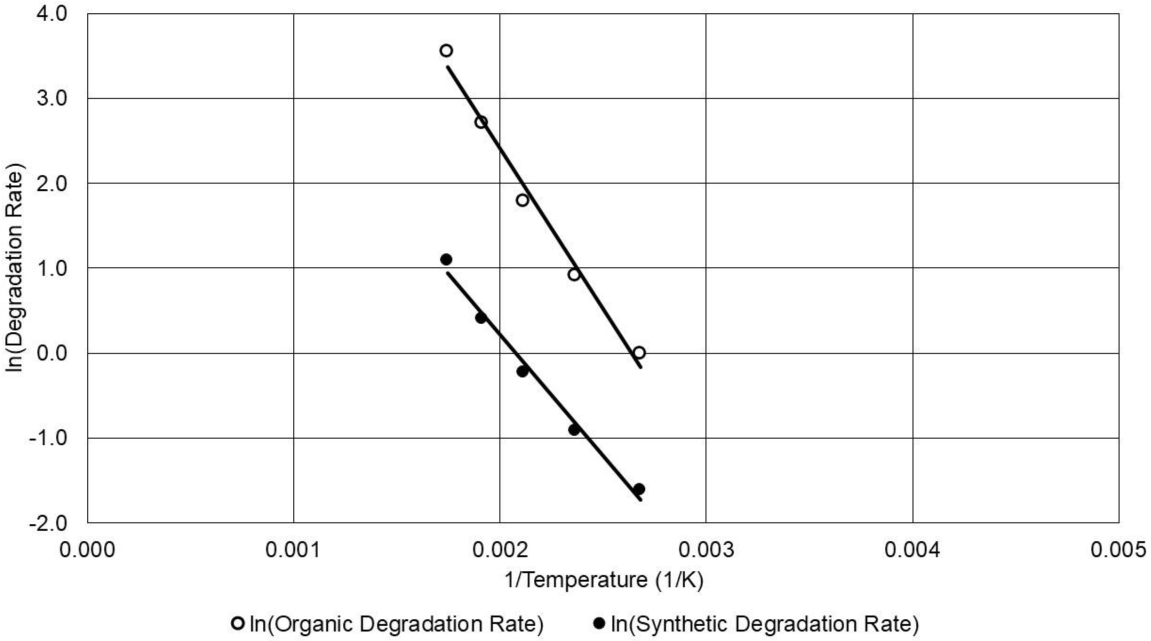

Figure 1. Hypothetical depiction illustrating the degradation of synthetic and organic heat transfer fluids according to the Arrhenius equation. Notes: a: Estimated degradation rate; Calculated using the natural logarithm of the degradation rate: $\ln(\text{degradation rate}) = \ln(A) - Ea / (R \times T)$. ln(degradation rate), is the natural logarithm of the rate at which the fluid degrades; A, is the pre-exponential factor (frequency of effective collisions); Ea, is the activation energy (in joules per mole); R, is the universal gas constant (8.314 J/mol·K); T, is the absolute temperature (in kelvin).

In this example, the synthetic HTF demonstrates superior thermal stability and longevity compared to the organic HTF, as shown by the consistently lower degradation rates across the full range of temperatures. This includes values below zero on the y-axis up to a temperature of 200 °C/392 °F, which indicate extremely low degradation activity. These values reflect a lower frequency of thermally activated molecular breakdown events—that is, fewer molecules possess sufficient energy to overcome the activation barrier at moderate temperatures. This property suggests that the synthetic HTF is significantly less susceptible to degradation under typical operating conditions, owing to its higher activation energy and inherently slower reaction kinetics.

Figure 1 and **Table 2** show that the synthetic HTF has a higher activation energy (~20 kJ/mol higher than that of the organic HTF). This higher energy barrier implies that significantly more thermal input is required to initiate degradation, again supporting its enhanced resistance to thermal degradation at elevated temperatures. These conclusions are drawn from the comparative analysis of ln(degradation rate) versus 1/T trends, which reveal a shallower slope for the synthetic HTF, consistent with slower reaction kinetics and greater thermal resilience.

Table 2. Estimated degradation, activation energy, and longevity for the two hypothetical heat transfer fluids.

	Organic fluid			**Synthetic fluid**		
Temperature, °C/°F (Kelvin)	ln(Degradation rate) [a]	Estimated activation energy (kJ/mol) [b]	Estimated longevity (h) [c]	ln(Degradation rate) [a]	Estimated activation energy (kJ/mol) [b]	Estimated longevity (h) [c]
100/212 (373.2)	0.00	65	100	−1.61	85	500
150/302 (423.2)	0.92	65	80	−0.92	85	400
200/392 (473.2)	1.79	65	60	−0.22	85	300
250/482 (523.2)	2.71	65	40	0.41	85	200
300/572 (573.2)	3.56	65	20	1.10	85	100

Notes: [a]: Estimated degradation rate. Calculated using the natural logarithm of the degradation rate: ln(degradation rate) = ln(A) – Ea / (R × T). ln(degradation rate), is the natural logarithm of the rate at which the fluid degrades; A, is the pre-exponential factor (frequency of effective collisions); Ea, is the activation energy (in joules per mole); R, is the universal gas constant (8.314 J/mol·K); T, is the absolute temperature (in kelvin). Values were extracted from **Figure 1**. [b]: Estimated activation energy. Calculated using the linearised Arrhenius equation: ln(k) = ln(A) – Ea / (R × T), where the slope of a plot of the natural logarithm of the degradation rate (ln(k)) versus the reciprocal of temperature (1/T) corresponds to negative of the activation energy divided by the universal gas constant (–Ea/R). [c]: Estimated relative longevity. Calculated as being inversely proportional to the degradation rate: Longevity $\propto 1 / k$. This relationship assumes first-order degradation kinetics and constant thermal exposure.

In terms of longevity, it is estimated that these properties represent a four to five-fold increase in operational lifespan (**Table 2**)—benefits that are typically associated with reduced maintenance frequency, system downtime, and long-term operating costs. In terms of safety, the slower degradation rate minimises the formation of harmful byproducts, enhancing the safety of the system and preserving its long-term integrity. These advantages make synthetic HTFs a compelling choice for high-temperature plants where reliability, efficiency, and long-term stability are critical.

4. The impact of a fluid type on thermal degradation

The type of fluid used in a system influences HTF degradation and the frequency with which it needs to be analysed [34]. Indeed, the chemical composition of an HTF plays a critical role, as organic fluids are typically derived from petroleum or natural sources, while synthetic fluids are chemically engineered. This is linked, in part, to a fluid's purity, which can affect corrosion, fouling, and reduce heat-transfer efficiency [2]. The chemical composition of organic HTFs generally means they are more susceptible to oxidation and thermal cracking, especially at elevated temperatures, and require more frequent sampling than synthetic fluids [35]. Furthermore, synthetic HTFs generally exhibit better resistance to degradation compared to organic HTFs [6]. This is due to their higher thermal stability and lower propensity to form carbon deposits [2,36,37] (see **Table 3**). In terms of cost, synthetic fluids are typically more expensive than organic fluids [38].

Table 3. General comparison of organic and synthetic heat transfer fluids.

Parameter	**Organic HTFs**	**Synthetic HTFs**
Parameter	**Organic HTFs**	**Synthetic HTFs**
Branded fluid examples	Globaltherm M, Mobiltherm 605 Shell Heat Transfer Oil S (previous named Shell Thermia B), Perfecto HT 5 (red) (previously called Transcal N (red))	Globaltherm Omnitech, Dowtherm A, Therminol VP-1, Marlotherm SH, Helisol 5A, Jarytherm BT 06
Maximum operating temperature	Lower	Higher
Thermal stability	Lower	Higher (see **Table 4**)
Fouling tendency	Higher	Lower

Notes: HTF, heat transfer fluid.

Temperature range needs to be considered - specifically the highest and lowest operating temperatures - for any application. Synthetic fluids generally offer a wider operating temperature range than organic fluids [37], although operating temperature significantly impacts degradation rates irrespective of fluid type, with higher temperatures generally accelerating reactions, with a doubling of the oxidation rate for every 10°C increase [1], and necessitating more frequent monitoring at higher temperatures. Furthermore, based on their chemical composition, organic HTFs have a higher susceptibility to oxidation [25] and thermal cracking [32,39] and typically require more frequent sampling than synthetic fluids.

The viscosity of a fluid impacts the ease with which it can be pumped, with a lower viscosity being easier to pump and requiring less energy. Organic fluids tend to have a higher viscosity than synthetic fluids, and therefore need more frequent monitoring.

Application requirements (i.e., the required heat transfer rate, system pressure, and compatibility with the process materials [2]) and system design play an important role, with open systems exposing the HTF to oxygen, thereby increasing the need for more frequent monitoring than closed, inert systems.

Contamination with foreign substances accelerates degradation, making regular sampling crucial for detection and corrective action [1]. Fluid age also affects degradation, as accumulated byproducts can catalyse further reactions, potentially requiring more frequent sampling for older fluids.

Nanoparticles, suspended in base fluids like organic HTFs, enhance thermal performance by improving conductivity and heat transfer [40,41]. Their properties influence the selection of an HTF based on application needs [42,43]. However, nanoparticles can also interact with the fluid, potentially accelerating degradation through increased oxidative stress or particle-fluid reactions, necessitating careful consideration of stability and maintenance [44]. More recently, research has explored the complex behaviour of viscoelastic micropolar nanofluids, which exhibit characteristics of both viscous and elastic fluids [45,46]. Such fluids are reported to possess variable thermal conductivity, which allows them to adapt their heat transfer properties based on local temperature, potentially smoothing out thermal gradients. They also exhibit thermo-diffusion and Brownian motion, which enhance nanoparticle dispersion, energy distribution, and can reduce localised overheating. Other research [46] suggests these fluids may have a future role in engineering applications by enhancing thermal control through the fine tuning of: (1) nonlinear heat source/sink terms, which allow for spatially variable internal heating or cooling; (2) activation energy, which influences the rate of chemical reactions and thus overall thermal behaviour; and (3) micropolar and viscoelastic parameters, which affect how the fluid responds to shear and rotational forces. Hence, these fluids represent potential future options that require research in a real-life setting, but offer the potential to improve system health and management, and enhance long-term efficiency.

5. Comparing the thermal stability of different fluids

The thermal degradation and stability of an HTF over time are driven by a combination of chemical, physical, and operational factors. Sustained exposure to elevated temperatures, particularly when operating near or beyond its maximum bulk or film temperature, leads to chemical breakdown (i.e., thermal cracking, oxidation, polymerisation). Resistance to degradation is quantitatively assessed through several key indicators, such as the measurement of total acid number (TAN) under thermal stress, measured using ASTM D6743 or D2440. These tests reflect acid formation from oxidative or thermal decomposition, with values below 0.2 mg KOH/g considered excellent. Another indicator is low-boiler formation, which reflects molecular fragmentation into volatile compounds that reduce flash point temperature and increase vapour pressure. This is often tracked via gas chromatography or distillation. Flash point temperature stability, typically measured by ASTM D93, reveals how well a fluid retains its ignition threshold under ageing, and a significant drop suggests accumulation of volatile degradation products. Together, these metrics, in addition to test duration and temperature, form an overall picture of thermal resilience.

Synthetic fluids, such as Therminol VP-1, Dowtherm A, and Globaltherm Omnitech, demonstrate superior performance across all these dimensions, maintaining low TAN, minimal low-boiler content, and stable flash points even after 1000 h at 400 °C [18]. In contrast, mineral oils show rapid TAN increase, flash point temperature decrease, and sludge formation, underscoring the importance of both chemical formulation and rigorous testing in evaluating long-term stability. The relative thermal stability of synthetic and mineral-based HTFs has been researched previously and, based on TAN growth, flash point temperature, and carbon residue (indicators of oxidative degradation), fluids with a biphenyl-diphenyl oxide composition (e.g., Globaltherm Omnitech) were shown to be more stable than mineral based HTFs [6].

Table 4 compares the thermal resilience of HTF types across key degradation indicators that reflect long-term stability under high-temperature conditions (i.e., TAN, oxidative resistance, low-boiler formation, flash point temperature stability, and test temperature used to simulate real-world operating conditions). Together, these parameters provide an overall indication of thermal resilience for the various types of fluids used in industrial applications.

Table 4. Assessment of the thermal resilience of organic and synthetic heat transfer fluids.

Fluid	**TAN growth (mg KOH/g)**	**“Low-boiler” formation (% weight)**	**Flash point temperature stability**	**Test temperature**	**Oxidative resistance (TAN/viscosity increase)**	**Qualitative rating of thermal resilience**	**References**
Therminol VP-1	<0.2 (after 1000 h @ 400 °C/752 °F, ASTM D6743)	~2–3% over 1000 h	Stable (110 °C/230 °F remains consistent)	400 °C/752 °F for 1000 h	~0.1 mg KOH/g/~5–10% (Very Good–Excellent)	Very high	[19,47]
Dowtherm A	<0.1 (after 1000 h @ 400 °C/752 °F, ASTM D2440)	~2–4% over 1000 h	Stable with venting (113 °C/235 °F)	400 °C/752 °F for 1000 h	~0.1 mg KOH/g/~5–10% (Very Good–Excellent)	Very high	[47,48]
Therminol 66	<0.2 (after 1000 h @ 345 °C/653 °F, ASTM D6743)	<5% over 1000 h	Slight drop (170 °C/338 °F → ~160 °C/320 °F)	345 °C/653 °F for 1000 h	~0.2–0.3 mg KOH/g/~10–15% (Very Good)	High	[47,49]
Paratherm HE	~0.3 (estimated after 500 hrs @ 315 °C/599 °F)	<2%	Minimal change (>210 °C/410 °F)	315 °C/599 °F for 500 h	~0.4 mg KOH/g/~15–20% (Moderate)	Moderate	[50,51]
Organic HTF	>0.5 (after 500–1000 h @ 290–310 °C/554–590 °F, ASTM D2440)	>5%	Significant drop (~180 °C/356 °F → <150 °C/302 °F)	290–310 °C/554–590 °F for 500–1000 h	>0.5 mg KOH/g/>20% (Poor)	Low	[6,50]

Notes: “Low boilers” are formed when thermal degradation causes molecular fragmentation into smaller, more volatile compounds [28]. TAN, total acid number.

6. Key parameters for monitoring fluid degradation

Regular preventative maintenance plans, including routine sampling and chemical analysis, are crucial in the management of HTF condition and are effective for mitigating the negative impact of degradation on the fluid and the system itself. Proper sampling techniques are essential for obtaining accurate measurements of HTF degradation [39]. Some common methods for measuring degradation include: viscosity, which measures the fluid’s resistance to flow, indicating changes in its physical properties [52]; acidity, used to determine the presence of acidic byproducts from oxidation, which can cause corrosion [1,32]; flash point temperature, which measures the lowest temperature at which the fluid can vaporise to form an ignitable mixture in air, indicating flammability hazards [26]; and gas chromatography, which is used to identify and quantify the presence of light-ends and other degradation products [53], indicating the extent of thermal cracking [32]. Regular monitoring of these properties also helps to detect the early appearance of fluid degradation [54] and prevent system damage [55,56]. Indeed, fluid sampling enables prompt corrective actions to be taken based on analysis results. Corrective actions may include fluid top-up, filtration, or fluid replacement. System design is also an important consideration and includes insulation, layout, and component selection. These are crucial for minimising heat loss, ensuring efficient fluid flow, and promoting fluid longevity [57,58].

7. The frequency of sampling

As mentioned previously, organic HTFs typically require more frequent sampling than synthetic fluids [6]. A recommended starting point for organic fluids is semi-annual or quarterly sampling, with adjustments based on factors such as operating temperature, system design [59], and historical data. Like all fluids, synthetic HTFs will thermally degrade when operating at elevated temperatures for extended periods. It is recommended that these fluids be sampled at least annually [60], as this may suffice for well-maintained closed systems operating within recommended temperature ranges.

It is crucial to emphasise that these are general recommendations, and the optimal sampling frequency (i.e., the frequency of sampling to maintain values that are the same or near as those of a fresh HTF) for a specific system should be determined using sampling data and combined with a comprehensive risk assessment and cost-benefit analysis [61] of the plant. For example, the optimal sampling frequency for a newly built system will be quite different from that of an established one. In this case, irrespective of fluid type, frequent sampling is recommended so that baseline values can be established, enabling the initial fluid status to be monitored [62]. In the presence of known contaminants, there will also be a need to perform more frequent sampling (e.g., monthly or quarterly) [62]. In all cases, it is important to follow the manufacturer's recommendations for a fluid, as these provide specific guidance relevant to the fluid's chemistry and operating conditions.

8. Concluding remarks and recommendations

HTFs are essential for many industrial processes, but they are susceptible to thermal degradation, which can negatively impact system performance and longevity. Degradation is primarily caused by thermal cracking and oxidation, leading to changes in fluid properties and the formation of harmful byproducts. Organic HTFs are generally more prone to degradation than synthetic HTFs, and factors like operating temperature, system design, and fluid age also play a significant role. Regular monitoring of fluid properties, such as viscosity, acidity, and flash point, is crucial for detecting degradation early and taking corrective actions to mitigate its effects.

Effective HTF management is essential for maintaining optimal system performance. This includes selecting the right HTF for the right application, with the general rule being that synthetic fluids are more stable at higher temperatures than organic equivalents. It also requires optimising sampling and analysis, with sampling being conducted at least quarterly to obtain a representative indication of the fluid's health. This should include parameters that characterise degradation arising from thermal cracking and the fluid's oxidative condition. By understanding the mechanisms of thermal degradation and implementing appropriate management strategies, it is possible to maintain the lifespan of thermal fluids and systems, ensure safe operation, and help minimise operational expenditure.

This narrative review highlights the importance of sampling, but future studies should consider assessing fluid condition in real-time, as this allows for more accurate assessments of fluid health and system safety. Future research should also consider how viscoelastic micropolar nanofluids influence fluid condition over the longer term, and their cost-effectiveness versus more traditional fluids used in industrial applications.

Conflict of interest: No conflicts of interest to declare.

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