THE RIGHT TOOLS FOR SUCCESS

Edward Cass, Paratherm Heat Transfer Fluids, USA, evaluates top strategies for sustaining the performance of thermal fluids.

Thermal fluids, also known as hot oils, heat transfer fluids (HTFs), thermal oils, etc., are fluids used to generate high operating temperatures at low system pressures. They are used in numerous applications from manufacturing of plastics and wood, to food processing, tank heating, refinery processes and chemical synthesis. These manufacturing processes rely on a continuous, responsive heating system to maintain production. Thermal fluids fuel these production processes and therefore fluid quality plays a big role in the overall efficiency and uptime of the system. Despite their established track record of enhanced safety, decreased maintenance and improved temperature control over other heating technologies, thermal fluids are prone to degradation over time. However, there is a fine line between fluid degradation and fluid failure. While fluid degradation is inevitable, implementation of proper fluid and system management strategies can help avoid costly fluid failure. Sustaining optimal efficiency and performance of the thermal fluid is largely dependent on implementing

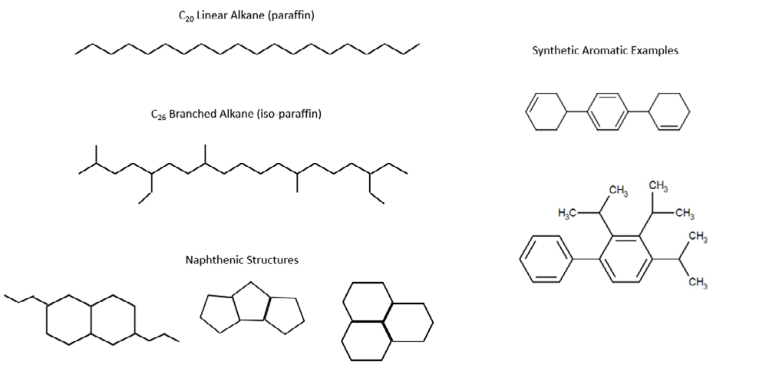

Figure 1. HTF chemistry – mineral oils are complex mixtures of paraffinic, isoparaffinic, naphthenic and aromatic structures. Synthetic aromatic fluids are high purity with more defined chemical structure.

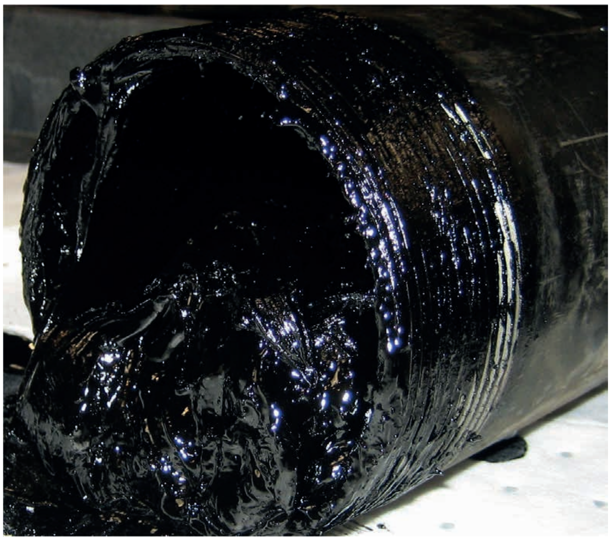

Figure 2. Oxidation and severe thermal degradation by-products will ultimately form sludge in the system.

a proper fluid management programme and understanding how to protect the fluid from the anticipated degradation pathways.

Why care about sustained performance?

Sustained performance from critical production equipment is invaluable to a business. Unplanned downtime can be one of the largest unexpected expenses a company endures, with some reports noting up to 20% of production losses as a result. The cost of downtime varies depending on the application, but most estimates suggest the cost of unplanned downtime can be in the tens of thousands of dollars per hour if not more. Many manufacturing facilities recognise this threat and have invested in proactive maintenance strategies for critical production assets. Despite the significant impact on sustained production, thermal fluid system maintenance is more often reactive rather than proactive, and costly downtime ensues. The bottom line is that thermal fluid system performance can be sustained - systems can operate predictably and efficiently with little to no unplanned downtime so long as good management strategies are followed.

Strategy one – select the proper fluid to match the application requirements

It is quite common to hear of the incorrect thermal fluid being used for a given application. One should beware of off-brand thermal fluids that are often re-labelled lubricant oils. In many cases, similar fluid chemistries may be used in both the heat transfer and lubricant oil worlds. Nonetheless, there are distinct stability differences between many of these fluids. When it comes to petroleum distillates (also known as mineral oil, organic hydrocarbons), it is critical that the end user stick with HTF's formulated from hydrotreated API Group II or better base oils, and that any additives used are stable to the process heat flux and will not catalyse fluid degradation or foul out on heat exchange surfaces. Fluid purity is paramount - slight differences in fluid purity can have amplified effects on surface deposits and coking propensity. Lower quality mineral oils are minimally refined, often dark in colour, and have a higher fouling proclivity at the film temperatures experienced in the heating equipment. While these fluids are less expensive up front, the long-term detrimental effects to process equipment should be considered. For liquid-phase service requiring operating temperatures of › 575°F (300°C), high temperature synthetic aromatic chemistries should be considered. These are benzene derivatives that take advantage of the enhanced thermal stability of the aromatic structure. Since these are synthetic chemistries, properties are tailorable based on the raw materials used, resulting in many product options offering a range of physical properties.

The ideal product for a given application/process will meet the following criteria:

- Easily meet the absolute minimum and maximum temperature requirements:
  - Proactively target a minimum 25°F cushion between maximum process temperature and maximum recommended operating temperature of the fluid when possible. For every 18°F above/below the recommended limit, the thermal stress on the fluid is doubled/halved, respectively. Building this cushion in helps to ensure the fluid can provide continuous service for a reasonable lifetime.
  - Consider of the lowest possible start-up temperature the fluid may experience given the local climate. This consideration in fluid selection can help prevent costly investment in heat tracing and/or freeze protection.
- Be compatible with all system and process components:
  - Consider compatibility with all piping, gaskets, seals, O-rings, etc., that the fluid will have direct contact

Figure 3. Perform a quick check of the fluid condition with a glass jar. The longer it takes for the glass to clear up, and/or the more sediment seen in the bottom of the jar, the more likely the fluid has undergone degradation. Send a sample in for full analysis.

with. Copper and brass should be avoided for all elevated temperature service.

- Provide reasonable performance and lifetime given the process conditions:
  - Performance of the fluid is contingent on purity, heat transfer efficiency and thermal stability. Do not be afraid to request performance data that can demonstrate these advantages.
  - Understand that proper operation and maintenance of the system can significantly impact fluid lifetime.
- Practice 20/20 foresight – investment in a better fluid up front may more than offset the price of replacing a cheaper, less stable fluid over time.
- Meet plant-specific safety and environmental policies:
  - Review the associated health and handling hazards and disposal protocol for each candidate fluid.

Strategy Two – understand the threats to continuous performance

The three most common threats to sustained performance of the fluid are thermal degradation, oxidative degradation and contamination.

Thermal degradation occurs when fluid molecules absorb more thermal energy than they can effectively release. The excessive thermal stress causes 'cracking' of the molecular bonds, resulting in irreversible damage to the fluid and subsequent changes in physical properties. The rate of thermal degradation is a function of fluid stability and energy flux at the heat source. As fluid molecules 'crack', they form lower boiling species (low boilers) which can also recombine to form higher boiling species (high boilers). Excessive low boiler accumulation will decrease thermal efficiency, viscosity and flash point and can also cause unexpected venting. The effects of excessive low boilers extend to equipment as well, with potential to cause pump cavitation subsequent seal and impeller failure, as well as general mechanical knocking of the system structure. As high boilers accumulate in the system, fluid viscosity may increase which can affect pumpability and thermal efficiency. Eventually solubility limits may be exceeded, and high boilers can precipitate out as sludge and tar, potentially fouling heat exchange surfaces or plugging lines. In severe cases, thermal degradation can lead to heavy coking and potential failure of heater tubes. Thermal degradation rates can be minimised in the following ways:

- Selecting the proper fluid based on the temperature requirements.
- Never exceeding the manufacturers recommended maximum temperatures.
- Ensuring adequate velocity of the fluid through the heater at all times. In addition, a routine preventative maintenance programme should be followed per the heater manufacturers recommendations.

Oxidative degradation occurs when hot fluid reacts with atmospheric oxygen in vented expansion tanks and reservoirs. Fluid oxidation can have significant impacts on fluid quality and performance. Oxidation produces organic acids which degrade into carbon soot and sludge over time if not corrected. As oxidation proceeds, the total acid number (TAN) of the fluid increases. Excessive acid accumulation can ultimately become corrosive, especially in the presence of small amounts of moisture. Over time, oxidation can cause an increase in fluid viscosity, precipitation of sludge and ultimately fouled surfaces and/or plugged lines in extreme cases. Accumulation of oxidation byproducts tends to lead to increased pressure drops, reduced flow, cold spots and reduced heat to the process. In most systems, oxidation can be eliminated by blanketing the expansion tank with an inert gas such as nitrogen. If blanketing is not an option, cold seal pots can also be considered as a relatively effective way of fighting oxidation. Despite being easily remedied, oxidation accounts for >90% of all premature fluid degradation cases.

Contamination is typically caused by process leaks, moisture ingress or operational error, such as adding the wrong fluid to the system, sharing process equipment or inadequate cleanout procedures. The effects of contamination depend on the specific contaminant. Moisture contamination tends to manifest itself quickly, leading to pump cavitation, unexpected venting or mechanical knocking. Other contaminants can have similar consequences as water contamination but can also manifest in different ways. In many cases, the contaminant may degrade rapidly, leading to increased acidity, creation of low/high boilers, carbon generation and/or fouling of surfaces. Process impacts may include decreased operational safety, reduced process flows, reduced heat to the process and even equipment failure in extreme cases.

Routine system reviews are invaluable to the heat transfer practitioners. One should walk the system once per week and pay attention to the sights and sounds. Keep an eye out for leaks, smoke, abnormal pressures or temperatures, etc. Small issues can quickly transform into larger problems, so it is important to address any abnormalities quickly.

Proper start up and shut down of the system is also critical for long-term performance. On start-up, the heater should remain in low fire until turbulent flow is established to prevent overheating. On shut-down, the main circulation pump(s) should remain running until the heater outlet temperature reaches 180°F or less.

Strategy three – implement a fluid maintenance programme

Condition monitoring of the thermal fluid is critical to sustained performance since unseen changes in fluid quality can impact the ability of the system to meet anticipated demands and can lead to unplanned downtime. Routine analysis alerts the end user to both the fluid condition and can also help detect equipment malfunctions before they become catastrophic. The goal is to establish proactive vs. reactive maintenance.

When to analyse the fluid

Newly commissioned systems should be analysed within the first year of operation. This can help aid in detecting any significant equipment issues that may be occurring under the radar. Existing systems should be sampled within the first month of start-up after re-charging to establish a new baseline for fluid properties. After that, it is highly recommended to sample systems at least once per year as part of a responsible management programme. In addition, any time a possible fluid-related symptom is observed, or when unexpected changes in performance occur, a fluid sample should be taken and analysed.

Critical tests for condition monitoring[1]

Critical tests for condition monitoring include the following:

Kinematic viscosity

Typically measured by ASTM D445 at 40°C, viscosity is a measure of the fluid's 'thickness', or internal resistance to flow. Viscosity increases are typically indicative of fluid oxidation, or potential contamination. Decreases in fluid viscosity are typically a result of thermal degradation or potential contamination. Changes in fluid viscosity that are greater than 35% from the new fluid value would indicate the molecular matrix has been compromised to some extent and may warrant partial replacement of the fluid to restore viscosity to optimal range. Changes greater than 50% indicate significant changes to the molecular matrix, and typically warrants full replacement.

Total Acid Number (TAN)

TAN is typically measured by ASTM D664. This is a potentiometric titration that uses a basic solution to neutralise the acids in the sample and indicates the total acidity. Acid number is indicative of the degree of oxidation the fluid has undergone, and/or indicates potential contamination. Acid concentrations as low as 0.2 mg KOH/g can begin to generate carbon in a system, while concentrations greater than 0.4 mg KOH/g are typically associated with higher levels of carbon loading. Acid numbers approaching or exceeding the condemnation limit of 1 mg KOH/g warrant full replacement.

Simulated distillation

Simulated distillation is typically measured by ASTM D2887. This analysis uses gas chromatography to separate all components in the fluid sample by boiling point. An increase in low/high boilers relative to the new fluid baseline indicates changes in the molecular matrix as a direct result of fluid degradation and/or contamination. Elevated low boilers are typically a result of overheating of the fluid, while elevated high boilers can indicate overheating, accumulation of oxidation by-products and/or fluid contamination. Action thresholds for low and high boilers vary, but generally low boilers in excess of 5 – 10% warrant action, and high boilers in excess of 10% warrant action. Low or high boilers in excess of 12% should warrant immediate action.

Moisture

Moisture is typically measured by the Karl Fisher coulometric titration technique. This method is capable of rapidly determining dissolved and free water content of organic fluids. Moisture content should be kept low in high temperature thermal fluid systems. Moisture content of new thermal fluids is typically quite low depending on the specific chemistry. In general, mineral oils are typically < 100 ppm water when new, and aromatics may be as high as 400 ppm when new. Increases in moisture outside of the new fluid specification indicate an ingress problem somewhere in the process or could have been introduced by adding contaminated make up fluid.

Conclusion

Sustaining performance of thermal fluid is a combination of sound management principles. It is essential to choose the right fluid for the operating requirements, minimise or eliminate the threats to fluid degradation, and perform routine condition monitoring of the fluid and preventative maintenance of the equipment. When these are done synergistically, maximum performance of the fluid becomes the status quo.

Note

1. Additional tests for fluid quality such as flash point, insoluble solids and density are often provided or referenced, but are not considered 'critical' for determining overall fluid condition.