NO LONGER A *mystery*

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Cover story

Edward Cass, Paratherm Heat Transfer Fluids, USA, helps to demystify thermal fluid properties and system operation.

There is often a lot of confusion and misconception surrounding heat transfer systems, how they are used, and how to properly take care of them. A lack of understanding can lead to fear and trepidation in system operators. This fear is often exacerbated when systems suddenly develop a problem after years of trouble-free operation. When trouble does arise, there tends to be a lot of misguided explanations or expectations about how the system should work or what fluid should be used. Thermal fluid systems utilise a combustible liquid at elevated temperatures and moderate pressures, meaning that some degree of caution is warranted. It is important to be educated on proper operation and maintenance as well as fluid selection criteria to reduce the potential for incidents and prevent misinformation from spreading.

Demystifying thermal fluid properties

All major thermal fluid suppliers provide technical data sheets that highlight important fluid properties. Depending on the supplier, these data sheets may be quite simple with only four to five key properties, while others may be full technical dossiers with pages of data. In practice, all properties have their place, but the following explanation of key properties will help demystify some of the terms often used.

Maximum fluid temperatures

Every heat transfer fluid product bulletin shows a maximum recommended operating temperature and/or a maximum recommended film temperature. If a heat transfer fluid data sheet does not contain this information, it is not explicitly designed for heat transfer service and should be avoided. Many manufacturers set the maximum operating temperature by subtracting 50°F from the maximum recommended film temperature, and the maximum recommended film temperature is usually determined based on industry standard stability testing.

Heat moves from the heat source (heater tube, electric element or steam coil) through a thin, relatively stagnant film of fluid into the moving fluid (bulk flow). If the temperature of this fluid film exceeds the maximum recommended film temperature, the bonds holding the molecules together start to break apart and the fluid will degrade. However, every heater has two film temperatures: the average and the maximum.

The average film temperature is estimated by dividing the average heat flux (Btu/hr-ft^2) by the fluid film coefficient (Btu/hr-ft^2-°F) and then adding that number to the operating temperature. If the heater has a uniform heat flux (e.g. steam coils, electric element, or flue gas heat recovery), the maximum film temperature will closely track the average.

However, almost all fired heaters have a radiant section which can have a much higher heat flux. This can result in localised film temperatures well in excess of the heater average. Depending on the fired-heater design, temperature differences between bulk and film temperatures can be as high as 100°F. This means that if the required operating temperature is within 60 – 75°F below the stated maximum film temperature of the heat transfer fluid, fluid life might be shortened.

Minimum fluid temperatures

Minimum fluid temperatures are typically reported as minimum operating temperature, minimum start-up temperature, pumpability and/or pour point depending on the manufacturer. The key thing to consider is the lowest temperature that any part of the process will experience. The circulation pump needs to be capable of moving fluid at its highest possible viscosity depending on the environment, otherwise heat tracing may be required. In practice, most heat transfer systems utilise centrifugal pumps which are typically only effective for viscosities below 400 centipoise (cPs). This therefore tends to set the low temperature limit. If the fluid will be used for cooling as well as heating, it is important to consider the temperature corresponding to the minimum viscosity where a fluid will efficiently transfer heat. For most equipment, the maximum design viscosity is around 20 cPs. This therefore usually sets the lowest operating temperature.

Coefficient of thermal expansion

This is a critical property for determining how the volume of the thermal fluid will change as it heats up. The expansion design must account for adequate expansion volume otherwise the system can overflow at full operating temperature. Most hydrocarbon thermal fluids experience a volumetric expansion of 4 – 6% per 100°F.

Flash point

Flash point is a property that often gets scrutinised after an incident occurs. Whoever is reviewing the incident will often see that the flash point of the fluid is below the operating temperature and determine that this is why the fire has occurred; however, this is usually not true. It is normal for thermal fluids to be used above their flash points because the conditions that promote a flash of the fluid are almost never simultaneously present in well-designed systems. The fire triangle informs that for a flash (fire) to occur, oxygen, fuel and an ignition source are all required. Unless the fluid is being operated above its autoignition temperature, an external ignition source would be required to initiate a flash. In addition, oxygen is only ever present in vented expansion tanks/reservoirs which run well below the flash point of the fluid. In the very rare instances that thermal fluid fires do occur, it is almost always due to poor maintenance practices and/or equipment failure.

Table 1. Secondary properties of heat transfer fluids

Property	Significance	Meaning
Viscosity	Moderate	Most hydrocarbon thermal fluids are relatively low viscosity, which is better for flow mechanics and heat transfer efficiency
Density	Low to moderate	Higher densities are favourable for heat transfer efficiency. Synthetic fluids often have higher density vs mineral oils giving them a slight efficiency edge
Moisture	Moderate	High water content can create serious headaches at extreme temperatures. Most heat transfer fluids have moisture levels below 300 ppm when new
Vapour pressure	Low	Vapour pressure is directly related to the boiling range of the fluid. Most heat transfer fluids have very low vapour pressures and high boiling ranges even up to their maximum use temperatures

Figure 1. When selecting an appropriate heat transfer fluid, the ambient environment of the system must be accounted for. If any of the system is located outdoors, low temperature startup conditions may apply.

Other properties

Table 1 highlights several other properties often reported in technical data sheets and their relative significance. Most of these properties can be considered secondary as far as their significance in the fluid selection process. Reputable heat transfer fluid suppliers have already done the work to determine the appropriate operating limits for their fluids, meaning that the secondary properties are the inherent manifestation of the temperature capabilities of the fluid.

The most important properties of the heat transfer fluid are the recommended temperature limits set by the manufacturer. If the fluid can handle the design temperatures of the process, all other properties are usually accounted for in the equipment design. For existing systems requiring fluid replacement, the replacement fluid should be the same or nearly equivalent based on the recommended operating range and chemical compatibility and should have similar physical properties to match the design criteria for other system components (heater, pumps, valves, etc.).

Demystifying heat transfer system operation

Thermal fluid systems are often neglected or forgotten about because they tend to perform reliably until a catastrophic failure of the fluid or equipment occurs. Like other process equipment, catastrophic failure can be avoided with a good preventative maintenance programme and good operational knowledge. The following tips may be invaluable for the heat transfer practitioner.

Charging the system

All control valves, block valves and high point vents should be opened where possible. A small positive-displacement pump should be connected as close to the pump suction as possible to fill from the bottom up. Bottom filling will substantially reduce the entrainment of air, a common cause of pump cavitation. Fluid should be added until the expansion tank is about half-full, and the block valve throttled to 25% on the main pump discharge for cold circulation (or cycle a gear pump on and off) to prevent pump damage. More fluid can be added as needed if the low-level switch trips, or if the pump starts to cavitate. Once the fluid is circulating steadily through the entire system, the pump can be opened to discharge to 50% or so. The system is full when the pump discharge pressure is steady at 100% flow. The expansion tank should be topped off as needed to maintain 66 – 75% level with the system at normal operating temperature.

System contaminants

New systems may contain contaminants from manufacturing and installation, while existing systems may have degradation by-products (carbon, sludges, varnishes, etc.) circulating with the fluid. Many contaminants can be removed with a standard 60-mesh strainer upstream of the pump. Additionally, most systems will benefit in the long run with a side-stream filtration loop to continuously remove contaminants and degradation by-products. It is important to ensure that the components are rated for the process temperatures. Water is the exception, which is typically introduced during 'hydrotesting' of the equipment, temperature cycling in vented systems or via a leaking heat exchanger. The most effective way to remove water is by performing a boil-out to vaporise the moisture out of the system. This can be tricky to achieve depending on the system configuration, so it is best to contact the original equipment manufacturer (OEM) of the heater or the fluid supplier for more information on how to do this.

System startup and shutdown

Improper startup and shutdown of the system can lead to rapid and premature degradation of the thermal fluid and equipment. All thermal fluids become less viscous as temperature increases. As the fluid gets thinner, its efficiency increases dramatically. At temperatures below 100°F, most high-temperature thermal fluids have viscosities greater than 10 cPs and will not flow efficiently. At startup, this cold fluid is not able to flow as well and absorb as much heat from the heater tubing compared to when it is hot. If the temperature rises too quickly, the fluid film at the heated surface may begin to crack, damaging the fluid on a molecular level. If the system has a repeated on-duty off-duty cycle, this damage will re-occur with each start-up. When cold, it is recommended to always start the system raising the heater setpoint in 10 to 20°F increments until the fluid reaches turbulent flow.

Figure 2. Multi-pass helical coil fired heaters are widely used in heat transfer applications for their thermal efficiency. Ensure that the maximum temperature ratings on the fluid are capable of handling the radiant heat generated inside the firebox for all fired heater designs.

Figure 3. Pressure gauges are an invaluable and inexpensive tool for monitoring the performance of the system. Take care to protect the gauges by installing sufficient tubing to dissipate heat.

During operation, the heater's refractory and structural metal will get almost as hot as the flame itself. If the entire system is shut down at once, the heater will stop firing and the pump will cease to move the fluid. The intense heat stored in the heater's refractory and structural metal cannot quickly exit the exhaust stack and remains in the firebox, scorching the heater tubing and cooking the thermal fluid inside.

It is very important when shutting the system down to turn the heater off but keep the circulating pump running. When the heater outlet temperature has decreased to 200°F or lower, it is generally safe to shut the pump down. It is recommended to keep the heater blower running if possible. By forcing cool air into the firebox, heat can be more quickly pushed out of the stack.

Simple instrumentation

While pressure gauges do not provide the data for actual flow calculations, they can track valuable information for troubleshooting. For example, a Y-strainer blockage can be detected with a compound pressure/vacuum gauge installed on the pump suction before it becomes a major problem. Similarly, a malfunctioning control valve can be readily detected by pressure gauges installed on the inlet and outlet lines of a heat user. Pressure gauges can also be used for certain functions which are vital to overall system performance. For example, if there is more than one user on a loop, a three-way control valve mounted on the bypass leg can equalise the user pressure drop. Pressure gauges should be located at the end of the supply header, the beginning of the return header, at the heater inlet and outlet, at pump suction and discharge, and also before and after every heat user (between the control valve and the user). Pressure gauges should always be installed with enough connecting tubing to dissipate heat. Moreover, to ensure that the gauge can be easily removed for maintenance or purging of solids, the installation of a block valve is recommended.

Fluid analysis

Many hot oil horror stories occur because the fluid was not analysed regularly. Routine analysis helps to monitor the quality of the fluid, but can also help catch mechanical failures before they become catastrophic. It is strongly recommended to analyse the heat transfer fluid at least once per year with the supplier. The analysis should be specific for heat transfer fluid and should include an explanation of the condition of the fluid as well as appropriate recommendations on how to move forward.

Conclusion

These explanations and tips should help to elevate the heat transfer practitioner's working knowledge of both systems and fluids. It is important to check the candidate fluid data sheets to confirm that critical properties are provided and appropriate given the operating conditions. When it comes to system operation, the guidelines for properly charging the system, and startup and shutdown procedures should be followed. Filters and instrumentation should be installed where needed, and the fluid should be analysed annually to keep an eye on critical properties. With all of this taken into consideration, the fluid and the system will continue to perform reliably without any major problems. T&T