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Cost Management in Heat-Transfer-Fluid Systems

By taking ownership of fluid-related decisions for the entire life of the project, from design through dismantling, users can secure the best and lowest-cost approach in process heating and cooling.

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In a perfect world, optimal heat-transfer performance would be achieved without compromise. Systems would require minimal heat-exchange surface area, with minimal cost associated with heat exchange equipment, and safety factors allowing for deterioration of performance over time would be unnecessary.

In the real world, however, economic losses can begin as early as the preliminary design phase. The design must accommodate uncertainties and assumptions, adding to the project's capital investment and operating cost.

But determining the optimal design is only the first in a series of critical decisions toward operating a cost-effective system. Numerous avenues of deterioration from peak performance can erode economics during the life of the system and of the fluid. Over time, conditions may vary, equipment wear may occur, and system modifications and/or additions may be imposed; yet, the original demands on the heat-transfer system may remain — or even increase.

When selecting the best fluid for the application, it is important to consider factors such as the initial-fill purchase cost, replacement frequency, top-up rates and oxidative stability. Awareness of in-service fluid condition will help identify potential fluid performance problems and allow proactive actions to be taken to avoid problems. With experienced technical support, the high costs associated with equipment corrosion, pump seal failures, unplanned downtime and compromised energy efficiency can be greatly reduced or eliminated.

This article discusses the key issues in the process development, design, and operation of a cost-effective heat-transfer system, including: design requirements of the system; fluid selection; heat-transfer performance; technical support from the heat-transfer-fluid manufacturer; environmental, safety and health (ESH) issues; operating costs; fluid replacement and disposal; and dismantling costs.

Basic system design requirements

The design requirements of the system are fundamentally defined by the process. Most organic heat-transfer fluids themselves require no exotic metallurgy, and can be safely used without corrosion of carbon steel for many years. However, sometimes the process fluid may require more specialized materials of construction. Exotic metallurgies should always be examined for temperature and chemical compatibility with the heat-transfer fluid. Consult with the fluid manufacturer for help in making these determinations.

The basic components of liquid-phase systems are an expansion tank, heater (or heat-recovery source), circulation pump and piping, process users of heat and/or cooling, and side-stream filter (optional). Vapor-phase systems will also include flash tanks, a condensate return system, and pressure control systems. Although vapor-phase systems can be quite large, the required fluid volume is less than that of comparably sized liquid-phase systems due to the density differences of fluids in liquid vs. vapor phases.

Filtration is optional, but applicable for both liquid- and vapor-phase systems. Side-stream filtration units are typically made of carbon steel, and are sized to accommodate 1–2% of the total circulating flowrate. When designing a new system without filtration, it is wise to make provisions for adding filtration in the future by installing the necessary piping connections before commissioning.

Since hydrocarbons are combustible, the system design should incorporate features to minimize the potential for fire. Fires in operating systems, although relatively rare, have resulted in significant downtime and replacement costs, loss of production, and risk of injury to personnel.

The most common cause of heat-transfer-fluid-related fires is ignition of fluid-soaked, porous insulation at elevated temperature. The environment under the insulation weather barrier can permit the slow oxidation of components in the fluid to form new compounds with lower autoignition points, and these can spontaneously ignite.

Some systems, such as in pharmaceutical processes, can require cooling to temperatures of –100°C and lower. Most cooling fluids have very low viscosities, and can also have very low flash points.

To minimize the potential for leaks and the costly consequences:

- Minimize the number of potential leak points (flanges and other connections).
- Specify graphite-based gasket sealing materials for fire resistance.
- Minimize or eliminate threaded connections.
- Use Class 300, raised-face flanges for effective metal ring gasket seating.
- Install closed-cell insulation in areas with the highest risk of leaks.
- Do not use flexible hose as a substitute for permanent, rigid piping.
- For applications with wide temperature variations, design flexibility into the system's piping based on stress analysis.
- Consult the insurance provider's requirements for other fire protection needs.
- Refer to appropriate design codes to determine area electrical classification requirements.

Fluid selection

Proper fluid selection is critical for long-term, trouble-free operation. It is easy to select the cheapest fluid based on purchase price alone. However, this approach can have costly pitfalls. It is essential to assess long-term operating costs, which can be multiples of the original cost of the system fill.

One typically selects a fluid based on the heating requirements of the process and the manufacturer's maximum bulk-temperature rating for the fluid. Since costs are typically higher for fluids with higher bulk temperature ratings, choose a fluid that meets or slightly exceeds the bulk temperature requirement — *i.e.,* buy only the amount of thermal stability required.

The fluids available on the market today represent a variety of chemistries and different thermal stabilities and capabilities. The figure illustrates average thermal stabilities of four major chemistries — partially hydrogenated terphenyls (PHT), alkylated aromatics, mineral oils, and a eutectic blend of diphenyl and diphenyl oxide (DP:DPO).

At temperatures near the rated maximum, a fluid's thermal degradation rate increases dramatically. This is true of all chemistries. A rule of thumb is that the thermal stress is reduced by about 50% for a 10°C temperature reduction while operating near the fluid's maximum. Thus, operating below the rated maximum bulk temperature can extend the fluid's usable life.

Long-term performance depends on more than thermal stability. Synthetic fluids, for example, tend to be more forgiving in oxidizing environments, because they are more resistant to oxidation and have greater solubility for the products of oxidation. Petroleum-based fluids, although more vulnerable to oxidation, can sometimes incorporate inhibitors to resist oxidation. These inhibitors require periodic refreshing, as their thermal stability is less than that of the heat-transfer fluid itself. Petroleum-based fluids can also generate significant sludge and fouling problems that can lead to increased downtime and clean-out expense.

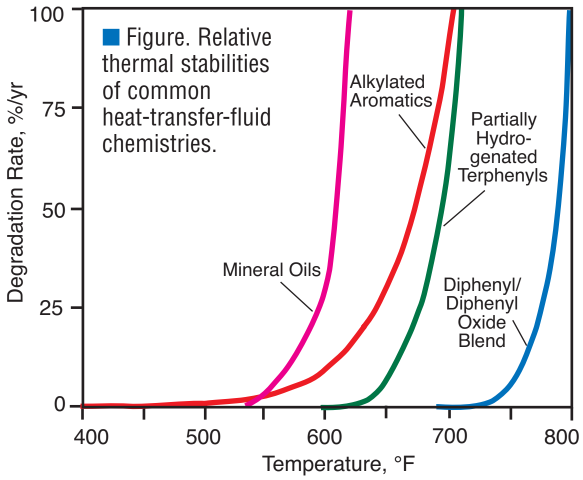
Oxidation tends to increase viscosity, which translates to reduced heat-transfer coefficients and reduced energy efficiency. Even with synthetic fluids, it is best to protect against oxidation by using an inert gas blanket on the system expansion tank. Inert gas blankets are very effective at preventing oxidation. A variety of oxygen-free gases have been used, but typically dry nitrogen gas is used.

Another important consideration in fluid selection is the compatibility of the heat-transfer fluid with the process stream, should intermixing occur. Consider possible chemical interactions, ease of separation, and other consequences when choosing a heat-transfer-fluid chemistry.

Heat transfer performance

System performance depends on the fluid-side and process-side heat-transfer coefficients. If the process-side coefficient is much less than the fluid-side coefficient, then the choice of heat-transfer fluid has less impact on the overall heat-transfer coefficient. For systems where the fluid-side coefficient drives the heat-transfer rate, the key properties relating to performance are, in order of significance: density, thermal conductivity, heat capacity and viscosity.

Most fluid manufacturers offer fluid analysis services to monitor in-service fluid condition. The tests are performed



■ Figure. Relative thermal stabilities of common heat-transfer-fluid chemistries.

using standardized test methods at ambient or otherwise safe and controlled conditions in the laboratory. Results are compared to results of virgin-fluid tests conducted under the same conditions. These data are used to assess the fluid's capability to acceptably perform at operating temperatures.

Representative samples have shown that most in-service fluid properties are fairly stable as they are thermally stressed, with less than 3% variation under test conditions. Viscosity, however, can deviate by as much as 300% or more (at 100°F) over the life of the fluid. The mechanism of viscosity variation is based on subtle changes in chemical composition that occur as the fluid degrades. As a guide, roughly a 10% increase in viscosity at operating temperature can cause a 3–4% decrease in the fluid-side heat-transfer coefficient, which can consume the same percentage of excess heat exchange area. Increased viscosity can not only affect heat-transfer rates at elevated temperatures, but may also impact low-temperature pumpability in colder environments.

When selecting a fluid:

• Buy only the amount of thermal stability required — there is no need to over-specify.

• Protect the fluid in the expansion \tank with an inert gas blanket.

• Consider non-routine upsets and their potential impact on thermal stability and fluid life.

• Weigh the value of factors beyond the cost of the fluid itself (technical support, sample analysis, etc.).

The best guidance regarding in-service fluid condition is obtained directly from the fluid manufacturer. Exercise caution when dealing with fluid reprocessors who lack the necessary expertise. Reprocessing introduces opportunities for contamination with other chemicals. It may also provide a disappointingly low yield of reclaimed fluid, and the physical properties may deviate significantly from those of the original fluid.

Technical support

Technical support from heat-transfer-fluid manufacturers should be considered a significant asset. Technical support specialists face issues daily that an individual user may see once or twice in an entire career.

Support services can include consultation on chemical interactions, fluid conditioning and/or analysis, industrial hygiene, design reviews, training, and others. It is difficult to assign a value to the services and expertise behind the fluids, but they can significantly enhance the total value of a heat-transfer-fluid purchase.

Environmental, safety and health issues

Environmental, safety and health (ESH) issues should be at the forefront of heat-transfer-system design and operation. Industrial hygiene monitoring should be conducted in areas handling mineral oils and any synthetics with permissible exposure limits (PELs) established by the U.S. Occupational Safety and Health Administration (OSHA). Since heat-transfer fluids are contained within essentially closed systems, concentrations in the air are typically well within the exposure limits.

Fluid manufacturers can offer guidance on some exposure measurement techniques. Best practices incorporate methods such as photoionization detectors to help identify leak points and prioritize repairs. Instruments currently on the market are capable of measurements at parts-per-billion (ppb) levels to enable real-time industrial hygiene monitoring. It may not be possible, though, for such instruments to discern among multiple organic compounds present.

Industrial hygiene monitoring is a small investment, but it pays large dividends over a plant's life. Benefits from effective monitoring and leak detection programs include leak point identification and repair, a healthful workplace, housekeeping improvements, fire prevention, and better maintenance planning.

Containment of fluids should also be considered an essential part of system design. Someone at the facility should keep abreast of federal, state and local regulations that may prescribe requirements for proper storage and handling of oils. Containment dikes and/or curbs not only make clean-up simpler in the event of spills, but may also allow a more complete recovery of the fluid, reduce potential reportable releases and reduce waste.

Because vapor-phase systems must be designed to accommodate pressurized service, their leakage potential is higher than that of traditional liquid-phase systems. Releases of pressurized hydrocarbon vapors at high temperatures into ambient environments can quickly cool to form clouds of mist droplets. Well-designed water-fog sprays have demonstrated effectiveness at quickly removing such mist clouds from the air. For indoor applications, ventilation enhancements and leak-detection and repair programs to minimize airborne concentrations and maintain a tight system should be considered.

Instrumentation, alarms and interlocks provide fundamental safeguards in process design. Most packaged fluid heaters are equipped with a standard set of instrumentation that meets minimal safety needs. Standard system alarm/interlock points include: stack temperature, pressure drop or temperature rise across the heater coil(s), liquid level (low/high) in the expansion tank, and liquid flowrate. Properly sized overpressure protection devices designed to relieve pressure to a safe location should also be included. Periodic testing of the safety devices and controls will help ensure their proper operation, which can prevent the occurrence of undesired events and minimize losses if such events do occur.

Fluid disposal involves cost and regulatory considerations. For example, spills to the ground require the clean-up of all contaminated soil and disposal as solid waste. Should the material spilled have any hazardous characteristics, it could require designation as hazardous waste. Heat-transfer fluids drained from systems may meet the definition of "used oil" under the U.S. Environmental Protection Agency's (EPA) 40 CFR Part 279, "EPA Standards for Managing Used Oil," which allow the fluid to be used for heat-recovery or other purposes. Some fluid manufacturers will accept the return of used fluids, facilitating the end-of-life disposition of the fluid.

Operating costs

The operating costs of heat-transfer-fluid systems are impacted by make-up rates, fouling, analytical support services, system cleaning, repairs, filtration, industrial hygiene monitoring, fluid disposal, and routine maintenance (interlock testing, relief device testing, etc.).

Fluid make-up rates are based on the thermal stability of the heat-transfer fluid during operation. Make-up fluid replaces fluid lost due to venting, maintenance activities, leaks, spills, etc. New systems have demonstrated annual make-up fluid-volume requirements as low as 3%.

System cleaning is sometimes necessary. In the past, a weak-acid/weak-base/water-rinse cleaning sequence was the most common cleaning method. It was moderately effective, but it involved the introduction of water into the system. Depending on the system design, the removal of water can be very slow. The entire process can require several days to accomplish the cleaning, followed by drying for several more days. Specially designed cleaning fluids enable a more rapid turnaround for cleaning and avoid the introduction of water.

For effective operation, baseline indicators of clean-system heat-transfer performance should be obtained early in the system's life. Monitoring these indicators over time can indicate the magnitude of deviations from optimal and clean-system performance, and quickly confirm when cleaning is justified.

System repairs can be expensive. Costs can be minimized by effectively scheduling repairs during planned downtimes.

Perhaps the most common unplanned repair is mechanical seal failure. Mechanical seals typically cost $1,000–$3,000 or more, excluding labor, etc. A proper installation should have a service life of 2 yr or more. Consult with the fluid manufacturer and seal provider for guidance on eliminating the root causes of seal failure — heat, pressure, corrosion and cavitation, all of which can lead to premature seal failure.

Any spark-producing work involving heat-transfer-fluid piping should be preceded by adequate decontamination of combustible residues as part of thorough pre-job planning and preparation. After completion of the modification, leak testing should be performed. System re-start should be carefully planned, taking into account that water might have entered the system while it was down. A violent response, including equipment damage, could result from the vaporization of water in a heat-transfer-fluid system. Proper start-up planning can prevent costly problems.

Filtration is a low-cost, high-benefit item. Glass-fiber cartridge-type filter elements are commonly used because they are of minimal cost and require replacement only a few times per year. This cost can easily be recovered by the sustained efficiency of heat transfer over time provided by clean heat exchange surfaces.

Other costs of maintaining the ongoing reliability of safety devices, relief protection devices, instrumentation, and fire protection systems should also be included in an overall cost assessment. These costs depend on the size and scope of the system and can vary widely. Performing these maintenance activities during planned downtime will limit these costs to the actual labor and any necessary repair or replacement of parts.

To maintain the best fluid performance:

- Follow the manufacturer's guidance on fluid maintenance.
- Avoid excessive accumulation of low-boiling and/or high-boiling components.
- Maintain effective filtration of insoluble solids.
- Protect against oxidation and contamination.

When the useful life of the fluid is over, the fluid can be drained from the system into drums or bulk containers for replacement and disposal. The most cost-effective disposition is determined based on the designation of the fluid. Most used mineral oils typically do not contain problematic hazardous compounds, and generally may be disposed of as used oil through the original supplier or an approved used oil processor. Synthetic aromatic heat-transfer fluids may similarly be managed as used oils, provided on-specification used-oil criteria are met in accordance with the applicable regulations.

Dismantling

The dismantling of an empty system involves three phases of work: decontamination, equipment removal and equipment disposal.

Decontamination of equipment that has been in heat-transfer service can take place once all fluid has been drained from the system. Care should be taken to ensure that the fluid is completely transferred from all piping into appropriate vessels, and that fluid is drained from all low points in the system. Equipment removal often involves some spark-producing work, so it is critical that combustible residues be cleaned from interior piping and vessel surfaces prior to equipment removal. Such cleaning also assists in preparing the equipment for disposal.

The most straightforward cleaning technique is an acidcaustic-detergent solution circulation, which involves circulating a dilute water solution of the cleaning agents throughout the system according to the supplier's directions. The dirty solution is drained and reserved for disposal according to local regulations. This multi-stage process typically ends with a water rinse.

The result of effective cleaning will be equipment adequately prepared for disassembly and disposal. Before cutting any piping, standard "hot work" procedures, including the use of explosion meter checks and use of a fire watch, should be followed. Piping and structural members may be sold as scrap, and vessels in good condition may be sold as surplus equipment to recover costs. Costs in the dismantling phase can be minimized by good planning to avoid unexpected events.

Final thoughts

By following these best practices in system design and making sound, informed decisions regarding fluid selection, total system costs can be minimized by:

- achieving fluid life expectancy
- minimizing fluid release potential
- employing essential system safeguards
- ensuring a safe and healthy workplace
- supporting process heat duty requirements.

An unexpected event that causes significant loss of property, run-time, and possibly life could easily be the single largest impact on total system cost. It is therefore essential to properly design and operate the system in a manner that anticipates and minimizes the potential for these events. Cost-effective management of heat-transfer fluid system design and operation can be enhanced by partnering with competent engineering firms and fluid manufacturers who offer extensive support for the life of the system. CEP

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