Cooling Electronic Circuitry With OptiCool Fluid

Operating Temperature Prediction
Increase in Cooling Performance and Temperature Profiles
Characteristics of OptiCool Fluid at Elevated Temperatures
Oxidation Resistance and Stability of OptiCool Fluid
Material Compatibility Studies

DSI Ventures, Inc.

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Introduction

There is renewed interest in liquid phase cooling of electronic circuit boards as a result of the introduction of liquid-cooled desktop computers and servers, as well as new, enhanced fluids now commercially available. One of these fluids that is receiving wide application is OptiCool Fluid DSI Ventures, Inc. This paper outlines the chemical, physical and thermodynamic characteristics of OptiCool Fluid and assists electronics manufacturers and owners in properly evaluating OptiCool as a heat transfer option.

Elements of Heat Transfer:

What makes one material more efficient at cooling or heating than other materials? There are several characteristics that contribute to a materials ability to do this; let’s look at the most important.

Heat Capacity:

What, exactly, is the heat capacity of a material, and how does it affect the cooling of a circuit board? Heat capacity is an intrinsic characteristic of a material, and refers to the amount of heat, measured in joules or calories, that must be input into a material in order to raise its temperature by a certain amount. Different materials hold different amounts of heat (again, measured in joules or calories), even when they’re at the same temperature. A good analogy is to think of standing in 65 degree air – it’s pretty comfortable. But if you jump into a swimming pool at the same 65 degrees, it feels really cold. That’s because air has a low heat capacity, doesn’t hold much heat. The temperature of air rises a few degrees with only a few joules of heat input, so it’s not a very good heat transfer medium. Water, however, has a high heat capacity, and can hold a lot of heat before its temperature rises. When you jump into the 65 degree pool, it feels much colder than the air did because the water has a high heat capacity and pulls the heat away from your body more efficiently. And so it is with heat transfer media; a high heat capacity makes for more efficient heat transfer, all other things being equal. Heat Capacity is known as Specific Heat when it is shown as a ratio between the heat capacity of a given material, divided by the heat capacity of water.

Conductive vs. Convective Heat Transfer:
If your cooling design consists of a pipe that’s in contact with the hot item, and fluid moving inside the pipe, that won’t be as efficient as fluid in direct contact with the hot item (in this case, a circuit board). That’s because the heat has to move in a “conductive” manner through the pipe itself to get to the fluid. Conductive heat transfer isn’t as efficient as “convective” heat transfer, which involves the fluid in contact with the hot item.

Velocity and Turbulence of Flow:
Another parameter of heat transfer is whether the fluid is moving and how fast it's moving, relative to its viscosity. A fluid that's moving will pull heat away from a hot item faster than one that's not moving. A fluid that's moving quickly will be more efficient at heat transfer than one that's moving slowly. If the fluid is moving slowly, then the flow across the hot item is probably "laminar", or smooth. If the fluid is moving quickly, then the flow is probably "turbulent". As you can imagine, fast moving, turbulent flow is more efficient. There is an equation that takes into account the fluid's viscosity, flowrate and other parameters and will tell you whether the flow will be turbulent or not by calculating a "Reynold's number" for the application. Reynold's numbers below 12 are considered laminar flow and those above 12 are considered to have turbulent flow.

The main take-away here is that a lower viscosity (thinner) fluid will be more efficient, if other things are equal, because its flow will be turbulent and have a high Reynold's number. So you want to choose a fluid with as low of viscosity as possible.

Low viscosity, though, is often a trade-off with flammability of the fluid. Thin fluids are usually more flammable than thick fluids. Gasoline, for example may be an excellent heat transfer medium, but it would hardly be a good choice to cool computers because of its dangerous flammability. So the viscosity of a fluid is often counterbalanced by other factors, such as flammability.

Heat Transfer Options:

Air:
Traditionally, forced air has been the primary cooling choice for electrical circuit boards. Air is inexpensive, easy to move, non-toxic and a good insulator, so the circuitry being cooled does not require additional dielectric insulation. Air, however, is not very efficient in transferring heat, due to its relatively low heat capacity (specific heat). Simply put, air doesn't hold as much heat and it therefore takes a lot of air blowing across a hot part in order to cool it. Air does not normally have any problems, though, with health, safety and the environment, nor with material compatibility.

Standard Mineral Oil:

Standard equipment oil and other mineral oils have been used in the past, but haven't been widely for several reasons. Although they're efficient in transferring heat away from a circuit board, they typically have low biodegradability and there are often problems with material compatibility. Many mineral equipment oils, for example, are excellent solvents, so they have a problem with delaminating circuit boards or dissolving rubber parts. Standard mineral oils are usually not highly biodegradable, and often cause an acne or other allergic reactions on the skin of those who work with it.

Fluorinated Fluids:

Fluorinated fluids, such as Freon®, are excellent heat transfer fluids. They have a very high specific heat, low viscosity and usually have good material compatibility. Fluorinated fluids are normally very expensive, however, and many have been discontinued because of concerns that their vapor can combine with ozone in the upper atmosphere, thereby depleting the ozone layer above the earth. Some fluorinated fluids can also decompose under an electric arc to create HF, hydrofluoric acid, which can be dangerously aggressive.

Vegetable Oils:

There are several vegetable oil-based fluids on the market now; their primary advantage is that they are highly biodegradable and environmentally friendly. Vegetable oils have satisfactory specific heat values, but their higher viscosity (the highest of the different liquids discussed here) often prevent them from being as efficient in heat transfer as a lower viscosity mineral oil. Most vegetable oils do not have the same oxidation resistance as mineral oils.

Synthetic “Petroleum” Fluids:

There are fluids that combine the best of many of the other types of oils available, without the associated drawbacks. These fluids are synthetic hydrocarbons – synthetic petroleum, if you will. Synthetic paraffinic hydrocarbons, such as isoparaffins and poly alpha olefins (PAOs) have high biodegradability, low flammability, and low toxicity. They have excellent resistance to oxidation, which makes them ideal for use as original fill fluids in electronics and industrial heat transfer systems.

OptiCool Fluid is a synthetic petroleum fluid. With very low viscosity, OptiCool cools equipment better than petroleum or vegetable oils. It’s highly biodegradable – just as environmentally friendly as the vegetable oils are – and it has a service life that’s longer than petroleum.

Factors Influencing Operating Temperatures in Power Circuitry

Equipment operating temperatures will be the result of four factors:

- The ambient temperature
- The heat transfer fluid's characteristics
- The design of the fluid flow – is there a path for fluid convective flow to occur? If so, what does it look like?
- The power load of the equipment – watts or joules dumped into the fluid

Other factors also influence the operating temperature, such as the size of the cooling ducts, if they exist, amount of heat transfer area (radiators), the operation of cooling fans, and oil pumps.

We will examine each of these factors individually, and then together.

1. The ambient temperature. In most designs, we assume an ambient temperature of 15^{o}C. Higher ambient temperatures will accentuate the performance advantage of OptiCool Fluid.

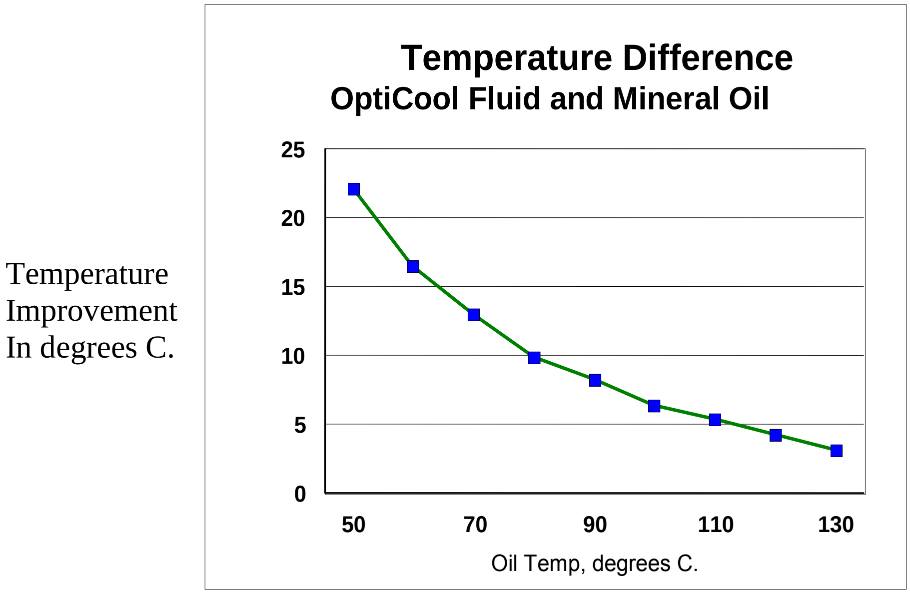
2. The characteristics of the heat transfer fluid. The physical and thermodynamic characteristics of the heat transfer medium have a tremendous effect on the ultimate operating temperature of circuit boards. Because of lower viscosity OptiCool Fluid more efficiently transfers heat than conventional equipment oil. Even with the power rating and the size of the equipment remaining equal, the equipment will run slightly cooler than it did with mineral or vegetable oil as the insulating fluid.

To predict the difference in operating temperatures due to viscosity effects alone, we have developed a sophisticated to estimate oil temperature.

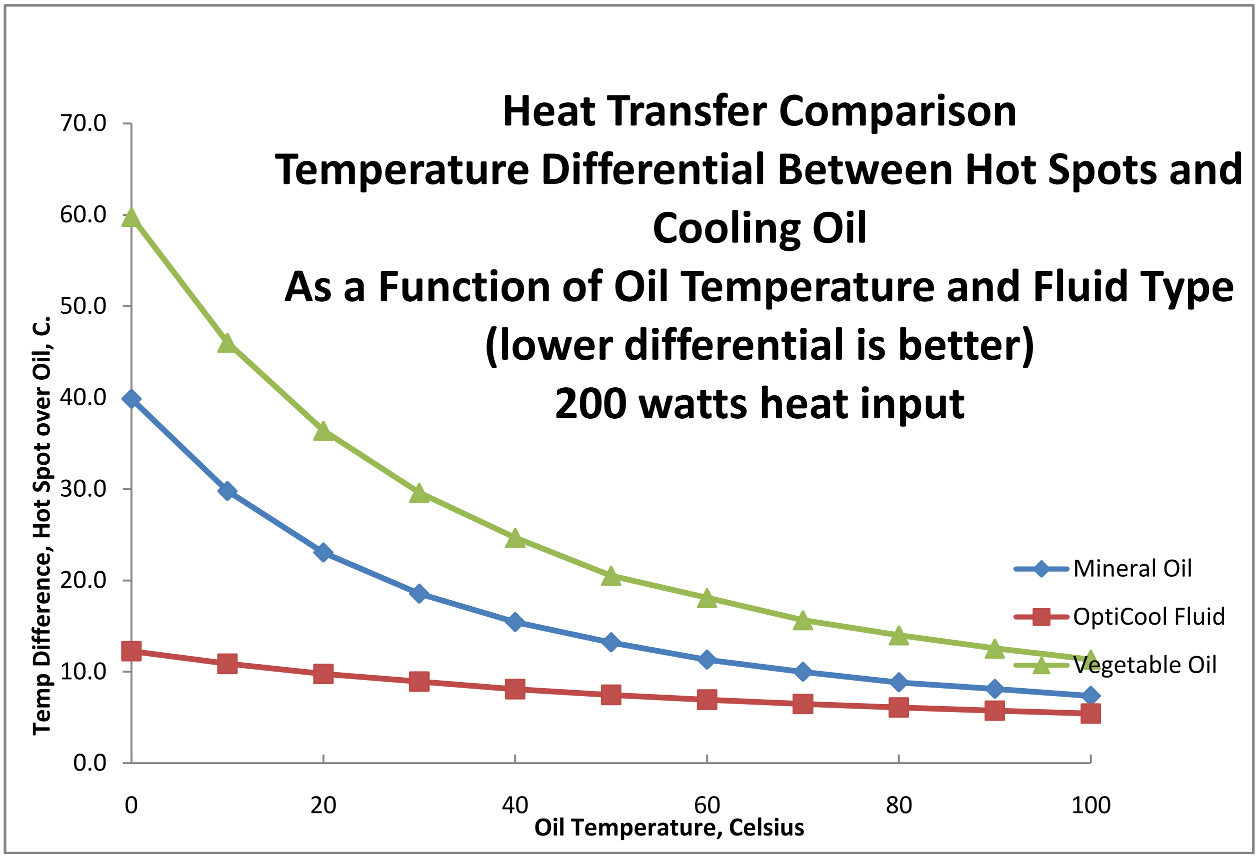
This computer model was developed by DSI and has been used successfully many times to predict operating temperatures in equipment cooled with OptiCool Fluid. It calculates fluid heat transfer parameters and uses information about the specific equipment to estimate the difference between hot spot temperature and insulating fluid temperature. An efficient heat transfer fluid will minimize this temperature difference.

The calculations are shown on the in the graph below (Figure 1). The data shows the difference in hot spot temperature (W) over oil temperature (O) for vegetable cooling oil, mineral cooling oil and OptiCool fluid.

The first graph below shows an example of the difference in operating temperatures when using OptiCool fluid instead of standard mineral oil dielectric fluid. Notice that the cooling enhancement of OptiCool Fluid is itself a function the oil temperature, and that the difference between the fluids is more pronounced at oil temps below 100 C.



The next graph shows, in greater detail, the difference in heat transfer capabilities of the three fluids. This graph shows the calculated difference in temperature between a hot component, such as a CPU, and the bulk of the heat transfer fluid. This particular model uses a 200 watt heat –generating component of 2x2 inches in size. Note that at all temperatures, the OptiCool Fluid maintains the lowest differential between the hot spot temperature and the fluid's temperature. In other words, it cools the hot spot more than the other fluids at all temperatures studied. It minimizes hot spot temperature.



As the operating temperature increases, the difference between the cooling performance of OptiCool and the other oils is decreased. In this particular equipment, when the oil temperature is 80 degrees C., the benefit of cooling with OptiCool Fluid is approximately 8 degrees C. over the same equipment when cooled with vegetable-based insulating oil. That is, the hot component temperature will be approximately 8 degrees lower when OptiCool is used as the cooling oil. Other equipment designs show similar results.

Other Considerations:

Resistance to Oxidation

Hydrocarbon oils oxidize when exposed to heat and oxygen. Buildup of acids and sludge can shorten the life of equipment. Sludge build-ups can block cooling ducts, hindering the flow of cooling fluid. Hydrocarbon fluids oxidize more rapidly when they are heated.

OptiCool fluid has exceptional stability because of its synthetic base oil. OptiCool fluid ages much more slowly than conventional petroleum based oil. Table One, below, shows the amounts of acids and sludge formed when OptiCool Fluid and mineral oil are tested in a standard ASTM Oxidation Stability test. This test shows that mineral oil oxidizes 40 times more quickly than OptiCool Fluid, which indicates that the OptiCool Fluid will last approximately 40 times as long in service as the mineral oil.

Characteristics of OptiCool at Elevated Temperatures:

The physical, chemical, and electrical characteristics of OptiCool fluid at different temperatures are shown in Table 2. There is very little change in the electrical characteristics of OptiCool with respect to temperature.

Table 1
Oxidation Results for OptiCool Fluid
ASTM D2440 oxidation test (bubbling O_2, 110 ^oC., Cu wire catalyst)

Standard Value for	OptiCool Fluid	Mineral Oil
72 Hours		
Sludge, wt %	<0.10	0.10
Acid Value Mg KOH/g	<0.10	0.30
164 Hours		
Sludge, wt %	0.010	0.020
Acid Value Mg KOH/g	0.010	0.40

Table 2
OptiCool Fluid Characteristics at Elevated Temperatures

Parameter	80°C.	120°C.
Density, g/cc:	0.7746	0.7434
Kinematic Viscosity, cSt:	2.17	1.52
Coefficient of Expansion:	0.00073/°C.	0.00071/°C.
Dielectric Strength, ASTM D1816, kV:	53 kV	54 kV
Dielectric Constant	2.12	2.05
Dissipation Factor, ASTM D924, %:	0.001	0.0012
Impulse Breakdown, kV:	> 300	>300
Specific Resistivity, ohm-cm:	1.1×10^{14}	4.0×10^{13}
Specific Heat. J/g/K	2.35	2.50
Thermal Conductivity, W/mK:	0.132	0.130

Compatibility with Equipment Construction Materials:

OptiCool Fluid is compatible with all circuit board and electronics equipment construction materials that are used with conventional mineral oil. OptiCool Fluid is less aggressive to paints, varnishes, rubbers, and other materials than is conventional oil. OptiCool Fluid is compatible with all gasket materials that are commonly used with conventional mineral equipment oil. Some of these materials are:

Nitrile Rubber	Silicone Rubber
Buna-n Rubber	Viton
Cork	Fluorocarbon Rubber

OptiCool Fluid is compatible with a wide variety of plastic insulation. OptiCool Fluid has been used with many types of phenolic, epoxy and formaldehyde resins. Both conventional and high-temperature insulating paper (Nomex) have been used in equipment filled with OptiCool Fluid.

Conclusion:

This study has examined the effect of using OptiCool Fluid to cool electronics equipment. Calculations show that the use of OptiCool Fluid will minimize the operating temperature of the components. OptiCool is a widely used dielectric heat transfer fluid, having excellent electrical insulating characteristics as well as heat transfer characteristics. OptiCool lasts longer in use, too - OptiCool Fluid oxidizes much more slowly than conventional mineral oil. OptiCool will create only 2.5% (1/40) as much acids and sludge as mineral oil in the same conditions.

References:

ANSI/IEEE Standard C57.12 "Standard Guide for Loading Mineral Oil Insulated transformers"

"Insulating Materials for Design and Engineering Practice"; F.M. Clark

"Electrical Insulation"; British Institute for Electrical Engineers