TECHNICAL BULLETIN

INTRODUCTION TO DIELECTRIC HEAT TRANSFER FLUIDS

O/FF-24

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INTRODUCTION TO DIELECTRIC HEAT TRANSFER FLUIDS

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Preface

The information in this booklet is intended as an introduction to the subject of dielectric heat transfer fluids. Additional information can be obtained from any of the several textbooks covering this subject matter. For heat transfer these would include:

Elements of Heat Transfer -- Jakob & Hawkins
Heat Transmission — W. H. McAdams
Introduction to Heat Transfer — Brown & Marco

While the above textbooks contain some information on flow dynamics, more complete information on this subject is available from the following:

Handbook of Fluid Dynamics — V. L. Streeter
Design of Hydraulic Control Systems — Lewis & Stern
Fluid Power and Control Systems — E. C. Fitch, Jr.

In addition, the various mechanical and chemical engineering handbooks have sections devoted to heat transfer and fluid dynamics.
In the following pages, reference is made to many of the physical properties of fluids such as viscosity, specific gravity, density, etc. For additional information on these properties and their method of measurement consult, "Introduction to Hydraulic Fluids" by R. E. Hatton or any of the engineering handbooks.
The particular test method for each physical property determination is indicated in the Coolanol technical data bulletin. A complete description of most test methods can be found in the ASTM Standards Handbook (Part 29, Electrical Insulating Materials).

R. A. Steenrod
September 1, 1970

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INTRODUCTION TO DIELECTRIC HEAT TRANSFER FLUIDS

Dielectric heat transfer fluids are similar to conventional heat transfer fluids with the added capability of operating in direct contact with the electrical circuit. Their major application is in airborne military electronic apparatus where, for technical reasons, water and air are not satisfactory (water because of its low boiling point, high freezing point and corrosiveness — air because of its poor heat transfer capability).

Selection of a particular dielectric heat transfer fluid involves consideration of the many technical parameters related to the product. As a matter of convenience, these have been divided into three main categories:

FUNCTIONAL (heat transfer, pumpability and dielectric properties)

OPERATIONAL (materials compatibility and service life)

SAFETY (flammability and toxicity).

In the FUNCTIONAL category, the following properties are included:

Density
Pour point
Viscosity
Thermal conductivity
Specific heat
Surface tension
Coefficient of expansion
Dielectric strength
Dielectric constant
Volume resistivity
Power factor
Lubricity

Under OPERATIONAL the following:

Neutralization number
Vapor pressure
Foaming
Hydrolytic stability
Radiation resistance
Water content
Thermal stability
Oxidative stability
Corrosion

Under SAFETY, are included:

Auto Ignition temperature
Flash point
Fire point
Toxicity

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HEAT TRANSFER

The major function of a dielectric heat transfer fluid is to transfer heat. The amount of heat transferred can be calculated from the expression:

$$Q = U A \Delta T_1 = M C_P \Delta T_2 \qquad \text{(EQUATION I)}$$

Where:

- Q = Heat flow
- U = Overall heat transfer coefficient
- A = Area of heat transfer surface
- ΔT_1 = Temperature difference between surface and fluid
- M = Rate of mass flow
- C_P = Specific heat of fluid
- ΔT_2 = Temperature change of fluid

Of major interest is the overall heat transfer coefficient, U, which determines the effectiveness of the fluid in the system. U, is composed of many factors including the very important one of film heat transfer coefficient, h. In many forced convection systems, h, is a controlling factor of the amount of heat that is transferred. Thus, an understanding of h, and its calculation is important.

Many equations are available for the calculation of h, (depending upon the nature of the fluid and the system). For purposes of illustration, the following equation has been selected. It is an average expression for a low viscosity fluid in a turbulent, forced convection system for both heating and cooling. It is quite probable that this equation would not be correct for all situations. Thus judgment is required for the selection of the correct equation for a particular design problem.

$$h = \frac{K}{D} 0.0223 \left(\frac{\rho V D}{\mu}\right)^{0.8} \left(\frac{C_P \mu}{K}\right)^{0.333} \qquad \text{(EQUATION II)}$$

Where:

- h = Heat transfer coefficient
- D = Diameter
- ρ = Density
- V = Velocity
- μ = Viscosity
- C_P = Specific heat
- K = Thermal conductivity

(The greater h, the greater the heat transfer capability of the fluid.)

The following is a discussion of the contribution of the functional properties to the heat transfer capability.

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Functional Properties

DENSITY

Density is the ratio of mass to volume and is an indication of the amount of matter contained in a specific volume of material. Since heat transfer involves the collision of molecules, it would seem logical that the more molecules available in a specific volume, the more heat transferred. This is the case; and is so expressed by Equation II in which heat transfer varies directly with the density. Thus, the greater the density the greater the heat transferred by the fluid.

VISCOSITY

Viscosity is a measurement of the resistance to flow of a particular material. Since heat is transferred through the flow of material it would appear that the greater the viscosity or resistance to flow the less heat that would be transferred. This is borne out as indicated by the reciprocal nature of heat transfer to viscosity in Equation II. Thus, the lower the viscosity the more heat transferred.

Viscosity is a most important property of a fluid. Viscosity usually changes more with temperature than any other physical property of a liquid. Thus, a consideration of the viscosity at the particular operating temperature of the liquid is necessary. For example: High viscosity usually limits the low temperature capability for a particular liquid. (This fact is the primary reason for the lower viscosity fluids in the Coolanol fluids product line.)

Viscosity, and the variation of viscosity with temperature, will vary widely with different types of liquids. The Coolanol fluids have excellent viscosity temperature characteristics and function well down to extremely low temperatures.

THERMAL CONDUCTIVITY

Thermal conductivity is an indication of the capability of matter to transfer heat by conduction. Thus, the greater the thermal conductivity the greater the heat transfer capability.

There is not a wide variation in thermal conductivity between different types of organic liquids nor within any particular class of organic liquid. For example, all of the Coolanol fluids have about the same thermal conductivity. Thus, this property is of lesser importance in determining the heat transfer capability of a particular fluid. The Coolanol fluids do possess good thermal conductivity.

SPECIFIC HEAT

Specific heat is an indication of the amount of heat required to change the temperature of a material. Thus, specific heat is an indication of

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the ability of a substance to store heat. As indicated by Equation II, the greater the specific heat the greater the heat transfer capability of the material. Specific heat, like thermal conductivity does not vary greatly from class to class or within the class itself. For example; the specific heat of all of the Coolanol fluids is about the same relatively high value of 0.45.

VELOCITY

While velocity is not a physical property of a fluid, it should be noted that the velocity of the fluid in the system is of prime importance in determining its heat transfer capability. For maximum heat transfer, the first consideration is that the velocity be great enough to insure turbulent flow in the system. Then once turbulent flow is established, the greater the velocity the greater the heat transfer capability of the fluid.

Of course, penalties are involved in creating high velocity in the fluid. The first of these is that more pumping power is required as the velocity increases. The second is that the pressure in the system must increase as the velocity increases. This aspect will be discussed in greater detail in the section concerned with pumpability.

In summary, regarding heat transfer capability in convection systems, the single most important physical property is the viscosity of the fluid. This is illustrated in the following table for heat transfer coefficient at 100°F for the various Coolanol fluids:

h, (heat transfer coefficient), BTU/hr. Ft.²°F.

Fluid	*h, at 100°F.*	*Viscosity, cs @ 100°F.*
Coolanol 45	210	14
Coolanol 40	270	6.5
Coolanol 35	270	6.5
Coolanol 25	340	4.2
Coolanol 20	440	2.0
Coolanol 15	460	1.6

(This heat transfer coefficient is for forced convection, turbulent flow (Reynold's Number greater than 2300) for a flow rate of 10 gallons per minute in one half inch smooth tubing.)

This table illustrates the dependence of heat transfer capability on viscosity; for the thermal conductivity, density and heat capacity are about the same for all of the Coolanol fluids and the only significant variable is the viscosity. However, just the variation in viscosity produces a difference of over 100% in heat transfer capability of the various fluids.

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PUMPABILITY

Pumpability is primarily concerned with the amount of power required to circulate the fluid through the system. This is dependent upon the quantity of the fluid, the pressure losses created by flow of fluid through the system and lubricating qualities of the fluid. In the functional category, our main concern is with the power required to circulate the fluid. The following equation relates pumping power to fluid and system parameters.

$$P_W = \triangle P \times A_C \times V \qquad \text{(Equation III)}$$

For turbulent flow:

$$\triangle P = 4f \frac{L}{D} \frac{\rho V^2}{2 g_c} \qquad \text{(Equation IV)}$$

And:

$$f = \frac{0.08}{\left(\frac{\rho V D}{\mu}\right)^{.25}} \qquad \text{(Equation V)}$$

Thus:

Power (P_W) is a function of density (ρ) and viscosity (μ).

Where:

P_W = Power
$\triangle P$ = Pressure drop
f = Friction factor
L = Length
ρ = Density
A_C = Area of cross section
V = Velocity
g_C = Gravitational constant
D = Diameter

Excepting the system parameters, it can be seen that pumping power is related to the pressure drop and the flow volume of the fluid. Furthermore, the pressure drop is directly dependent on the viscosity and the density; that is, the higher the viscosity and density, the more pumping power required.

The following is a brief discussion of the relationship of the functional properties to both the heat transfer capability and pumpability of the fluid.

DENSITY

High density is desirable from the heat transfer viewpoint but may be undesirable in regards to pumping power. Thus a tradeoff may be involved; and each system must be analyzed in order to determine the desirable density for the fluid. If the prime consideration is heat transfer capability and adequate pumping power is available, then a high density fluid would be desirable. If pumping power is limited, as it may be in an aerospace application, then a less dense fluid may be more beneficial.

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POUR POINT

Pour point is directly related to the low temperature capability of the system. In most applications, it is undesirable to allow the fluid to freeze; and the pour point would represent the absolute minimum temperature capability of the fluid.

VISCOSITY

Low viscosity is desirable from both the heat transfer and pumpability viewpoint. That is, the lower the viscosity the greater the heat transfer capability and the less pumping power required. However, lubricity may be adversely affected by low viscosity. In many instances, lubricity is inversely related to the viscosity so that as the viscosity decreases the lubricating qualities of the fluid tend to decrease also.

In most dielectric heat transfer systems, the lubricating requirements of the pump and components are modest and only minor consideration need be given to the lubricating qualities of the fluid. (The most commonly used heat transfer liquid is water, which is a poor lubricant but is still successfully used in many systems.) Lubricity is a complex function and cannot be easily related to fluid properties. Instead, bench and performance type tests are used to describe the lubrication qualities of a fluid. The Coolanols are considered to be good lubricants and should present no lubricity problems for most systems.

SURFACE TENSION

Surface tension is a fundamental property of a liquid and is related to its molecular structure. It is the tendency of the molecules of a liquid to draw together at the surface to form the smallest area possible. Surface tension is related to many aspects of fluid performance (lubricity, leakage, heat transfer, etc.) but theory has not been refined to the point where simple equations are available to quantify the relationship of surface tension to fluid performance. Both high and low surface tension fluids are used successfully in heat transfer applications and there does not appear to be an overwhelming advantage to either. The Coolanol fluids possess low surface tension.

COEFFICIENT OF THERMAL EXPANSION

The coefficient of thermal expansion is a measurement of the change of volume of a material with temperature. This property usually dictates the reservoir size for a particular system since, as the temperature of the fluid increases, its volume will also increase. Thus, allowance must be made in the system reservoir to accommodate the increased volume of the fluid at elevated temperatures. Since increased size and weight of the reservoir is required to accommodate the thermal expansion of the fluid, it is therefore desirable to utilize fluids with low thermal expansion coefficients.

DIELECTRIC STRENGTH

Dielectric strength is a measure of the ability of the fluid to withstand voltage stress and the higher the dielectric strength, the higher the

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voltage that can be impressed upon the fluid. In a dielectric heat transfer fluid, high dielectric strength is desirable and is usually the electrical property of greatest interest to the design engineer.

It should be noted that the dielectric strength of a liquid is usually quite dependent upon contaminants present in the liquid such as water or entrained air or gas. Water will have a deleterious effect upon dielectric strength particularly if ionizable impurities are present in the liquid for the water will allow these impurities to ionize and be affected by the electrical field.

Gas bubbles will also degrade the dielectric strength of a liquid primarily because the dielectric strength of a gas is so much lower than for a liquid.

The Coolanol fluids do have high dielectric strength and because of their chemical nature are quite exceptional in their toleration of water.

DIELECTRIC CONSTANT

Dielectric constant is a measure of the ability of the liquid to store electrical energy. This property is usually not of interest in dielectric heat transfer applications. The Coolanol fluids have relatively low dielectric constants.

VOLUME RESISTIVITY

This property describes the ability of the liquid to act as an insulator. If a fluid has very low volume resistivity it would be a conductor of electricity and not suitable for dielectric heat transfer applications. However, relatively low volume resistivity can be tolerated in most dielectric heat transfer applications. In most cases, the only result of the low volume resistivity is a slight additional heating of the liquid. The design engineer is usually not too interested in volume resistivity. His main concern is with dielectric strength and if the dielectric strength is adequate then the volume resistivity would usually also be adequate for the application. The Coolanol fluids have high volume resistivities and are good electrical insulators.

POWER FACTOR

This property is a measurement of electrical loss in the liquid. As the power factor increases, the electrical losses also increase; the net result being a heating of the liquid. In most instances, power factor is not of concern in dielectric heat transfer applications.

OPERATIONAL PROPERTIES

The second category, operational properties, is concerned with materials compatibility and service life of a fluid and system. The following is a brief discussion of the importance of various operational fluid properties on the performance of the fluid.

NEUTRALIZATION NUMBER

This number is an indication of the acid or base content of the system, the higher the number, the more acid or base in the system. This

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number is obtained by titrating a sample of the fluid with a standard acid or base solution and noting the amount of acid or base required for neutralization. Thus the neutralization number can be either acidic or basic. When acid it is often referred to as the acid number or when basic, the base number.

The acid content of the fluid usually increases with use due to thermal, oxidative and hydrolytic breakdown of the fluid. A high neutralization (acid) number is undesirable because it would indicate high acid content, which could lead to metal corrosion in the system and/or loss of dielectric strength in the liquid.

VAPOR PRESSURE

Vapor pressure is a measurement of the tendency of a liquid to evaporate. It also indicates the boiling point of the fluid (which is the temperature at which the pressure of the vapor equals the pressure of the atmosphere in contact with it).

High vapor pressure indicates that the fluid would evaporate rapidly if exposed to the atmosphere. It would also indicate that boiling could take place at relatively low temperatures. This boiling could be undesirable in many liquid phase heat transfer systems. Also, high vapor pressure could tend to promote cavitation of pumps. Thus, in liquid-phase systems low vapor pressure fluids, such as the Coolanol fluids, are desirable.

FOAMING

Foaming is an indication of the tendency of a liquid to entrain or encapsulate air or gas present in the system. Foam generation is undesirable because it degrades both the heat transfer capability and pumpability of the liquid; and excessive foaming could lead to damage of the pump in the system.

It should be noted that the presence of a gas or vapor is necessary for foam generation. Thus, if the liquid is gas and vapor free or if conditions in the system are such that all of the gas will remain in solution, then foaming will not occur.

Foam generation is undesirable in the system. The Coolanol fluids are low foaming liquids and should present no problems in most systems. Where foaming is a problem, thorough degassing of the fluid should be considered.

HYDROLYTIC STABILITY

Hydrolysis is the chemical reaction of the fluid with water. Hydrolysis could be harmful — or beneficial — depending upon the nature of the products of hydrolysis. If acid were formed, then hydrolysis would be detrimental to the fluid and system.

On the other hand, hydrolysis could be a desirable reaction if it removed water from the system and no harmful reaction products were generated for removal of the water would help maintain the dielectric strength of the liquid and system. This is the case with the Coolanol fluids.

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The Coolanol fluids are formulated silicate esters and hydrolysis of a silicate ester produces alcohol and a silicon containing polymer. Fortunately, both these reaction products have good dielectric strength. Thus, a silicate ester has the ability to consume water in the system and in doing so, maintain the good dielectric strength of the fluid.

Among all common dielectric fluids, this behavior is unique to the silicate esters. With most dielectric fluids, water has a very adverse effect on the dielectric strength of the liquid. For example: 80 PPM of water in a transformer oil or in askarel is sufficient to reduce the dielectric strength from a dry-fluid value of 50,000 volts to less than 5,000 volts (per a 100 mil gap).

Thus, great care must be taken with other dielectric fluids to minimize their contamination with water. If these fluids are contaminated with water, then processing is required to remove the excess water.

With the silicate esters, this great care and concern is not necessary for they tend to heal themselves when exposed to contamination by water. Likewise, they will tend to dry other materials in the system such as paper or plastic insulation. This behavior is quite beneficial in the maintenance of dielectric strength in the liquid and system.

RADIATION RESISTANCE

Radiation resistance is the ability of the fluid to withstand high frequency radiation. The source of radiation could be nuclear, or a high power transmitting tube. (Many transmitting tubes – and even some receiving tubes such as rectifiers in color TV sets – emit X-ray and other types of radiation.)

The behavior of a fluid under radiation is quite similar to its behavior under thermal stress. Thus a fluid that can withstand high temperature can usually withstand higher levels of radiation also.

Radiation resistance is usually not of great concern in most dielectric heat transfer applications. It may be where high power transmitting tubes are involved. In that case, high radiation resistance in the liquid would be desirable. The Coolanol fluids possess good radiation resistance.

THERMAL STABILITY

This property is an indication of the ability of the liquid to withstand heat in an oxygen-free environment. Fluids with poor thermal stability would break down rapidly at high temperature leading to the formation of volatile material, gels, and possibly acid. Good thermal stability is desirable in a dielectric heat transfer fluid.

There are many tests in existence used to measure the thermal stability of a liquid and judgment is required in applying the results of any particular test to a particular application for the product. The Coolanol fluids have excellent thermal stability.

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OXIDATIVE STABILITY

Oxidative stability is a measure of the ability of the fluid to withstand heat in the presence of air (oxygen). It differs from the thermal stability in that the fluid is kept saturated with air at all times so that abundant oxygen is available for the oxidation of fluid. Poor oxidative stability could lead to the rapid formation of sludge and acid in the fluid.

Good oxidative stability is desirable, but it is usually possible to design around poor oxidative stability in most dielectric heat transfer applications. A common means is to enclose the system and prevent entrance of air. In extreme cases, it may be necessary to evacuate the air from the liquid and operate the liquid in an inert environment.

Again, there are many tests in use to measure the oxidative stability of a liquid. Judgment is required to relate the results of a particular oxidative stability test to an individual application. The Coolanol fluids have good oxidative stability.

CORROSION

Corrosion is a measure of the affect of a liquid on various metals that might be in a system. Corrosion is usually measured in conjunction with the thermal or oxidative stability of the fluid. Corrosion is directly related to the rate, amount and type of acid formed in the liquid under thermal or other stress.

Corrosion is usually undesirable in the system as it may interfer with heat transfer. It could also lead to wear and deterioration of the metal components in the system. There are a number of tests used to measure corrosion and judgement is required in the application of test results to a particular system.

The Coolanol fluids are essentially non-corrosive.

SAFETY PROPERTIES

The last category is the safety characteristics of the product, particularly its flammability and toxicity. It is desirable to have a product with low flammability and a low order of toxicity. The properties usually selected to judge these characteristics are the auto-ignition temperature, the flash point, the fire point, and the toxicity of the product. A brief discussion of each follows:

AUTO IGNITION TEMPERATURE

The auto ignition temperature (AIT) (sometimes referred to as the autogeneous ignition temperature; and also as the spontaneous ignition temperature (S.I.T.)) is the temperature at which the liquid will ignite in the presence of air, but in the absence of an ignition source such as a spark or flame. It is used to indicate the behavior of the liquid coming in contact with a hot surface. The AIT is usually considerably higher than the flash and fire points of the fluid. A high AIT is desirable and the Coolanol fluids do have relatively high AIT's. It should be noted that the AIT depends upon the test method used. The AIT

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does *not* represent the minimum temperature at which combustion would take place in the absence of an ignition source. Under certain conditions combustion may occur below the AIT for the fluid.

FLASH POINT

The flash point is the temperature at which the liquid will just begin to ignite in the presence of air and a flame. A high flash point is desirable.

FIRE POINT

The fire point is the temperature at which the liquid will ignite and continue to burn in the presence of air and an ignition source, such as an open flame. A high fire point is desirable. The Coolanol fluids have relatively high flash and fire points.

FLAMMABILITY

There have been many tests developed to measure the flammability characteristics of fire resistant fluids. These include the high pressure spray, the low pressure spray, and the hot manifold test. Our currently available Coolanol dielectric heat transfer fluids are not considered fire resistant fluids and thus the special flammability tests are not run.

Instead, the flammability of these liquids is judged by reference to the AIT, flash and fire points of the liquid. This type of judgement is quite valid for flammable liquids, but could be quite misleading in regards to fire resistant liquids. For additional information, consult the booklet, "A review of Fire Resistant Test Methods for Aircraft Hydraulic Fluids".

TOXICITY

There are numerous tests in use to judge the toxicity of a product. Of particular concern is the effect of a product in contact with the skin or eyes or when eaten or inhaled.

Judgements on effects of this type are usually based upon test results with laboratory animals. This includes contact of the liquid with the skin and eyes of rabbits; ingestion and inhalation by rats and mice. In some cases, human agents are used for the skin contact work.

Another characteristic sometimes considered in the safety category is the noxicity of the product. Noxicity refers to any unpleasantness associated with the use of the product — bad odor (such as a fishy smell); eye watering (such as onion juice, for example); unpleasant feel to the skin, etc. Noxious characteristics do not necessarily indicate toxic characteristics of the product for it is possible for a product to be noxious without being toxic (for example, the taste and odor of fish

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is noxious to many, but, nevertheless, the fish is not toxic). It is desirable for products to have a low degree of noxicity, that is, to be as pleasant as possible to work with.

The Coolanol fluids are not noxious and have a low order of toxicity.

PHYSICAL PROPERTIES AND UNITS OF MEASUREMENT

In regards to the calculations for heat transfer coefficient and pressure drop, it is quite important that consistent units of measurement be used throughout; that is, either all metric units or all English units. This requires extreme care in the selection of data -- for physical properties are quoted in Metric and English units and sometimes in a hybrid system using features of both the English and Metric system.

The most generally used physical properties are listed in the table below in Metric units along with factors necessary to convert them into the English system.

Symbol	Property	Metric Units	Conversion Factor (Metric x factor) =	English Units
h	Heat transfer coefficient	cal/sec. °C cm^2	7373	BTU/HR°F $Ft.^2$
D	Diameter	cm.	0.0328	Ft.
K	Thermal conductivity	cal-cm/sec cm^2 °C	242	BTU-Ft./HR. Ft^2. °F
C_P	Heat Capacity	cal/gm °C	1	BTU/lb_m °F
μ	Absolute viscosity	gm/cm. sec. (poise)	242	lb_f/Ft. HR.
A	Area	cm^2	0.00108	Ft^2.
$\triangle T$	Temperature	°C	1.8	°F
L	Length	cm	0.0328	Ft.
ρ	Density	gm/cm^3	62.43	$lb_m/Ft.^3$
V	Velocity	cm/sec	118.1	Ft./HR.
P	Pressure	dyne/cm^2	1.45×10^{-5}	lb_f/in^2
g	Gravitational constant	1	—	$32.2 \frac{lb_m\ Ft.}{lb_f\ sec^2}$

lb_m = Pounds of mass

lb_f = Pounds of force

It should be noted that the viscosity used in these calculations is the absolute viscosity (poise or centipoise) not the kinematic viscosity (stokes or centistokes) we normally deal with. In the metric system, the absolute viscosity is obtained by multiplying the kinematic viscosity by the density; that is: cp = cs x ρ.

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HEAT TRANSFER CALCULATIONS

(Formula taken from: Elements of Heat Transfer, Jakob & Hawkins)

As mentioned previously, in dielectric heat transfer applications the purpose of the fluid is usually to transport heat from a source (load) to a sink (radiator) in order to cool the source (usually a transmitting tube) and keep it from overheating.

The amount of heat is normally related to time and expressed as heat flow (represented by the symbol, Q). Typical units are BTU/hour. As mentioned previously, $Q = U\ A\ \triangle\ T_i$; and an important part of the overall heat transfer coefficient, U, is the film heat transfer coefficient, h.

Usually Q is known (so much heat must be removed in order for the apparatus to work properly) and the U, A and $\triangle T$ must be adjusted to accommodate Q.

U, (and h,) is dependent on the nature of the heat transfer fluid, the pumping rate, the geometry of the system and other factors.

A is dependent on the geometry of the system.

$\triangle T$ is dependent on the heat source, the fluid; and the materials of construction of the system.

Very often, h, can be adjusted to obtain the necessary heat transfer and h, can be calculated through use of the many equations that have been developed for various fluids and systems. The typical equation for h, we are using is:

$$h = \frac{K}{D}\,0.0223\left(\frac{\rho VD}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{K}\right)^{0.333}$$

Where:

h = Film heat transfer coefficient, BTU/hr. Ft.²°F

K = Thermal conductivity, BTU/hr. Ft. °F

D = Diameter, Ft.

ρ = Density, lb./Ft.³

V = Velocity, Ft/hr.

μ = Absolute Viscosity, lb/hr Ft.

C_p = Specific heat, BTU/lb °F

The expression $\left(\frac{\rho VD}{\mu}\right)$ is the Reynold's Number.

The expression $\left(\frac{C_p\mu}{K}\right)$ is the Prandtl' Number.

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This equation is recommended for turbulent flow (Reynold's Number greater than 2300) low viscosity fluids and is an average expression for both heating and cooling.

A typical example follows:

Fluid:	Coolanol 25
Temperature:	100°F
Flow Rate:	10 GPM
Tubing size:	1 inch
Find h	

From Coolanol 25 Technical Data Bulletin:

$K = 0.075$ BTU/hr Ft. °F (31.2×10^{-5} cal/°c cm. sec x 242)

$\rho = 55.6$ lb/Ft.^{3} (.891 x 62.43)

$\mu = 4.2$ cs x .891 x 2.42 = 9.0 lb/hr ft

$C_p = 0.45$ BTU/lb °F

$$V = 10 \text{ GPM} = \frac{10 \text{ gal.} \times 60 \text{ min.} \quad \text{Ft.}^3}{\text{Min.} \quad \text{hr } 7.481 \text{ gal } .00547 \text{ Ft.}^2} = 14600 \text{ ft/hr}$$

$$h = \frac{0.075}{.083} \frac{0.0223}{} \left(\frac{55.6 \times 14600 \times .083}{9.0}\right)^{0.8} \left(\frac{0.45 \times 9.0}{.075}\right)^{0.333}$$

$h = 94$ BTU/hr ft^2 °F

Assume:

$Q = 100{,}000$ BTU/hr

$A = 20$ ft^2

$h = U$

Find: ΔT

$Q = U A \Delta T = 100000 = 94 \times 20 \times \Delta T$

$\Delta T = 53$°F

The second factor of importance to the design engineer is the pressure differential required to produce the desired flow rate. Pressure differential (ΔP) is important because pump size, pumping power and system integrity are all a function of it.

The greater the ΔP the larger the pump and the greater the pumping power required. Also tubing and components are designed for a maximum ΔP; and if this rating is exceeded they may rupture from the high pressure.

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Thus it is necessary to calculate the ΔP for the system. Again, many equations are available — depending upon the fluid and the geometry of the system. A typical equation for pressure drop in tubing for a low viscosity fluid in turbulent flow (Reynold's number greater than 2300) is shown below. (This pressure drop is not the total pressure drop for the system. Other losses in the system, such as losses in fittings, would have to be considered in order to arrive at the total pressure drop.)

$$\Delta P = \frac{4}{144} f \frac{L}{D} \frac{\rho V_1^2}{2gc}$$

Where:

$$f = \text{Friction Factor} = \frac{0.08}{\left(\frac{\rho VD}{\mu}\right)^{.25}}$$

ΔP = Pressure drop, lb/in²

L = Length, ft.

V_1 = Velocity, ft/sec.

$$g_c = 32.2 \frac{\text{lb. mass} \quad \text{ft.}}{\text{lb. force} \quad \text{sec.}^2}$$

Assume:

Conditions same as for calculation of h.

$L = 1$ ft.

$$V_1 = \frac{14600 \text{ ft}}{\text{hr } 3600} \quad \frac{\text{hr}}{\text{sec}} = 4.05 \text{ ft/sec}$$

$$\Delta P \text{ (per foot)} = \frac{4}{144} \frac{.08}{\left(\frac{55.6 \times 14600 \times .083}{9.0}\right)^{.25}} \frac{1}{.083} \frac{55.6\ (4.05)^2}{2 \times 32.2}$$

$\Delta P/ft = .041$ lb/in²

Assume 75 ft. of tubing:

$$\Delta P = .041 \times 75 = 3.1 \text{ lb/in}^2$$

Pumping power would be:

$$HP = \frac{\text{Flow (GPM)} \times \Delta P}{1714}$$

$$= \frac{10 \times 3.1}{1714}$$

HP × .018 Horse Power

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