Fluorotherm Polymers Inc.
www.fluorotherm.com

FLUOROTHERM®

An ISO 9001-2015 Certified Company

Immersion Heat Exchanger Coils for Corrosive/Ultrapure Chemicals - Choosing the Right Strategy

Introduction

Today, Immersion Coils for heating and cooling are available in a variety of shapes, materials, designs and assemblies from various manufacturers. Polymer (Polyethylene, High Performance fluoropolymer), common and exotic metal alloys, pancake coil shapes, racetrack coils, grid structures, spaghetti tube U bends, welded and non-welded tube terminations, and tube ends connected to a manifold are among the many options available. Less than fully informed decisions lead to suboptimal or wrong choices (for example, based on purchase price only). Such choices end up in faster than expected deteriorating performance or even catastrophic failure.

Among materials, fluoropolymer coils have been around for 40+ years, and have secured a unique position in a multitude of diverse industries that use heat exchangers for temperature control of corrosive chemicals and ultrapure liquids. This paper describes the important basics of heat transfer and provides comparisons between the options for you to ask the right questions to enable the best purchasing or replacement decision.

What are Fluoropolymers?

Fluoropolymers are thermoplastics with fluorine as part of their chemical structure. Most common plastics such as polyethylene and polypropylene have hydrogen in their structure. The substitution of hydrogen with fluorine imparts some unique properties, such as chemical inertness, high use temperature, flame resistance, low coefficient of friction, and "non-stick" characteristic, among others.

FEP, PFA PVDF, PTFE are among the more popular polymers, in addition to some others such as ETFE, PCTFE etc. The maximum use temperature, pressure rating, thermal conductivity, and flexibility are some of the properties that determine the best resin for use in a specific application.

Why Fluoropolymers instead of metals for heat exchangers?

While metal heat exchangers (made of carbon and stainless steel, copper, aluminum), and now low temperature plastic (polyethylene) are utilized in many commercial and household products, air conditioners and space heating for example, where corrosion or contamination may not be a serious concern, many industrial and specialty applications require the heating and/or cooling of corrosive acids, alkalis, organics. Radiant floor heating is an exception, and there is new interest in using fluoropolymers because of their long life – the low temperature rated tubes turn brittle are not readily accessible for repair after installation.

Fluoropolymers are ideally suited for facilitating heat transfer in chemically aggressive environments., common metal heat exchangers will not last very long when exposed to the liquid or vapor. Figure 1 shows an example of a fluoropolymer heat exchanger.

Fig. 1 - A Typical Immersion Coil Fluoropolymer Heat Exchanger[1]

A second type of application where fluoropolymer heat exchangers are used is where “very high or ultra-purity” is required. Heating and cooling of fluids by fluoropolymer coils is preferred when purity is of the utmost importance, for example in semiconductor processing where contamination from the heat exchange surface is unacceptable. In these cases, it is critical that the heat exchanger material does not corrode or leach into the chemical being processed.

Some exotic metal alloys are also used for heat exchangers, these include titanium, zirconium and Hastelloy™. These alloys are resistant to a restricted range of chemicals, unlike the broad, almost "universal" range of resistance of fluoropolymers. High alloys, especially zirconium, are relatively expensive, have thin walled tubes and are difficult to repair by welding in house, unlike some brands of fluoropolymer heat exchangers.

Fluoropolymer Immersion heat exchangers (loosely called Heat Coils or Immersion Coils) have been around since the mid 1960's, and was developed primarily for the metal finishing industries such as steel (sheet rolls production), galvanizing, wire and tube, and other steel products. Later, their applications spread to the chemicals processing, mining, extractive, coal power plant, semiconductor, metal plating, minerals, ore processing and numerous other industries.

The primary reasons dictating the choice of fluoropolymer heat exchangers are the following –

- They are corrosion resistant, unlike their metal and other material counterparts
- They can handle reasonably high bath temperatures, up to about 310 F
- Steam at pressures up to 80 psig can be used as a heating medium
- Fluoropolymers are ultrapure materials, their innate chemical inertness makes them unreactive to most chemicals, including organics.

There are several manufacturers of fluoropolymer immersion heat exchangers, though geometries, range of surface areas, and the maximum heat transfer capacities differ significantly. The essential component of such heat exchangers is the fluoropolymer tubing, assembled in a coil, as a bundle or in a grid form. The tubes or tube coils are supported by an open frame or housed in a perforated chamber. Properties of the tubing, therefore, are key to the performance and longevity of the heat exchanger, especially in view of the premium value of fluoropolymer heat exchangers compared to their low-cost steel or copper counterparts.

Basics of Immersion Heat Exchanger Design

As with any heat exchanger design method, the basic equations used are as follows –

$$Q = mC_p\Delta T + \text{External Heat Losses (due to ventilation, work load, etc.)} \qquad (1)$$

where, Q is the Heat Load per unit of time, m is the mass, C_p is the specific heat, and ΔT is the temperature change from the initial to the final temperature. The units of Q may be time based if the time required for the temperature change is known. External heat losses occur due to ventilation, conduction through tank walls, agitation, heat carried away by the work load, if any, that may be processed in a bath. Graphs and or equations to determine the external heat losses are available online. Some manufacturers use internal, proprietary information to estimate the external heat losses.

The basic design equation is,

$$Q = UA\Delta T \qquad (2)$$

where, Q is the heat transfer rate, U is the overall heat transfer coefficient, A is the heat transfer surface area, and ΔT is the temperature driving force (steady for continuous processes, variable for batch processes) between the service and the process fluids.

In the simplest design case, Q is calculated from Equation 1 as the required heat to be added (for heating) or removed (for cooling) and used in Equation 2 to determine the heat transfer surface area A.

In the equations above, the overall heat transfer coefficient, U, is key to the design and selection of an immersion heat exchanger as it is the only parameter that is partly determined by the choice of material.

<u>Understanding the Overall Heat Transfer Coefficient</u>

The thermal resistances encountered by the "flow of heat" from one area to another is important to the understanding of the meaning of the overall heat transfer coefficient, U. This coefficient is expressed as a number that is derived from the individual heat transfer coefficients, h. The individual coefficients reflect the thermal resistance of each zone (either at the interface or in the matrix of the material) through which heat has to pass through from the "colder" fluid to the "warmer" fluid. The fluids may be liquid-liquid, or liquid-gas or gas-gas. In the case of bath heating, the tube may carry hot water inside it as the heating or service fluid.

A simple graphic of the thermal resistances around an immersion exchanger tube inside a bath that is heated by hot water is shown in Figure 2 below.

The process requires the colder "process fluid" bath to be heated. Heat has to move from A. the hot water (forced convection) to B. the water-tube interface film, then C. pass through the tube wall (conduction), then D. across the tube-process fluid film, and finally E. to the bath (forced convection). Items A through E comprise the various resistances to heat transfer and thermal calculations take into account all resistances that can be represented as individual heat transfer coefficients (h). These coefficients are consolidated using appropriate formulas into an overall heat transfer coefficient "U" used in equation (2). Item C. above, conduction, is most commonly the main resistance to rate of heat transfer, and this is determined by the thermal conductivity and the tube wall thickness of the tubing material.

The coefficient, $h_{1,}$ represents the convective heat flow rate through the body of the hot fluid to the inside tube surface. The middle term in the resistance diagram represents the rate of heat flow through the tube wall (influenced by the material conductivity), and the third term, $h_{2,}$ corresponds to the convective heat flow to the cold fluid outside the tube. *(The thermal resistance is inversely proportional to the heat transfer coefficient).* The overall heat transfer coefficient, U, in this series of resistances is controlled by the highest resistance in the series., which is generally determined the tube wall thickness and material conductivity. Therefore, thermal conductivity of the tube material is an important parameter.

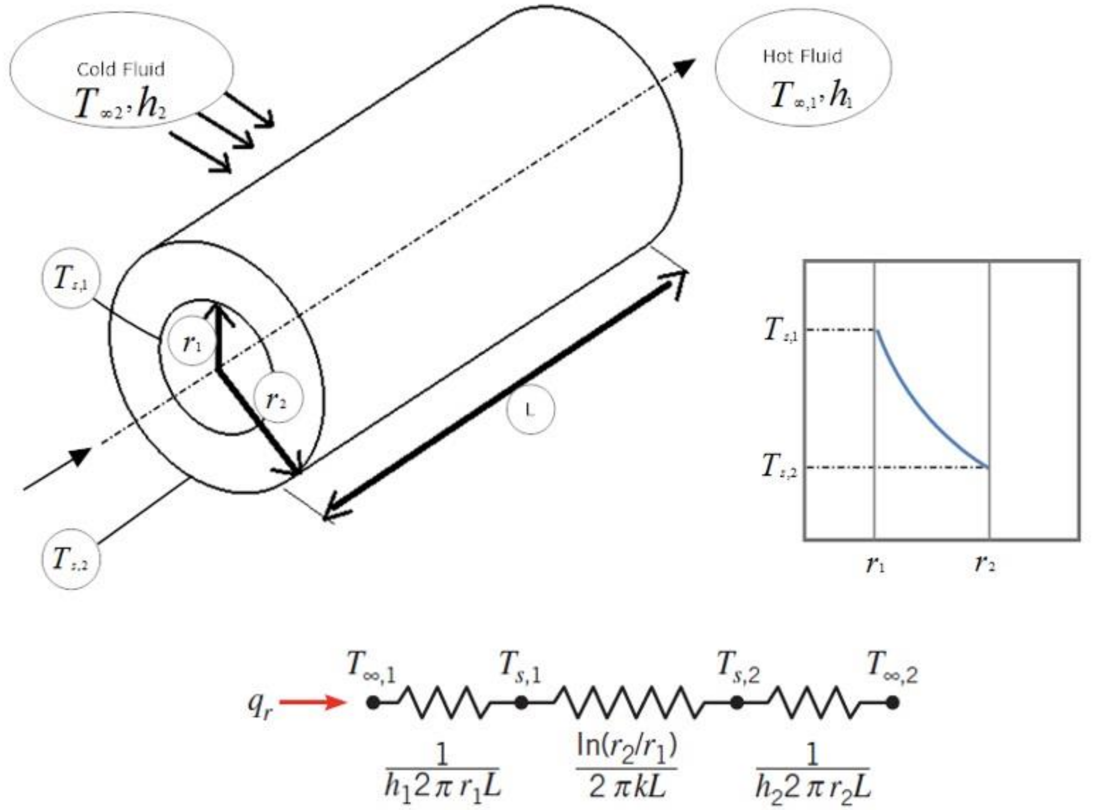

Fig.2 – Representation of typical Thermal Resistances in a Tubular Heat Exchanger[2]

Influence of Thermal Conductivity on Materials Selection of Immersion Heat Exchangers

It is well known that the conductivity of metals is significantly higher than plastics. However, the susceptibility of common metals to chemical attack strike them out as candidates where the bath liquid is an acid, or another corrosive or ultra-pure fluid. In these cases, exotic metal alloys, if considered, will work satisfactorily if they are compatible with the chemical in contact, and if there are low or no particulates that can stick to the heat exchanger surfaces. Adhesion of particles, such as salts, phosphates, dirt, and oxides to the heating or cooling exchanger surface creates a serious thermal resistance to the transfer of heat, which gets worse with time. Eventually, performance deteriorates to the point where the heat exchanger must be cleaned, or repaired if damaged, with the attendant problem of production downtime due to draining of the tank to remove the heat exchanger.

Fluoropolymers offer “almost” universal chemical resistance and “non-stick” property advantages over metal heat exchangers. Inhibition of particle sticking to surfaces allows both a steady heat transfer performance and longevity of use. These “performance in use” parameters must be taken into account during the heat exchanger materials selection for new and replacement installations. The lower thermal conductivity of fluoropolymers, compared to metals, is already “baked” into the design and sizing of new tanks, and many existing installations have replaced metal heat exchangers with fluoropolymer ones. *There are relatively new variations of fluoropolymer tubing with significantly improved thermal conductivity, and continuing work in this area continues to improve upon this key property, while minimizing the sacrifice of the native chemical inertness and “non-stick” characteristics of fluoropolymers.*

<u>Heat Load</u>
The total heat load, Q, (Equation 1) is normally expressed as Kcal/hour or Btu/hour or an equivalent unit, and must be determined as a first step in the design of a heat exchanger. All heat sources and sinks in the process should be identified. Examples of these are exothermic chemical reactions, electrical heat input, (heat addition), ventilation, agitation, heat absorption of materials processed in the bath (heat loss), convective heat loss from an open liquid surface, and conductive heat loss from the tank walls and bottom. Generic formulas or charts for quantifying these types of thermal additions or subtractions are widely available. It is important to ensure that the local environment, such as flow velocities, turbulence, unsteady state conditions be considered while using a published formula or chart.

<u>Flow</u>
The flow pattern and conditions inside a heat exchanger tube must be considered when determining the thermal resistance (or the local heat transfer coefficient h). This is important when steam or a condensable gas is used as the heating medium. If the steam is saturated and dry, condensation (phase change) begins to immediately occur when it enters the colder liquid in the bath. Part of the tubing however, is filled with the both steam (gas phase) and condensate (liquid phase), as shown below *(Source of Figs, 2 and 3 in Reference List)*

VISUALIZATION OF TYPES OF FLOW IN TUBES

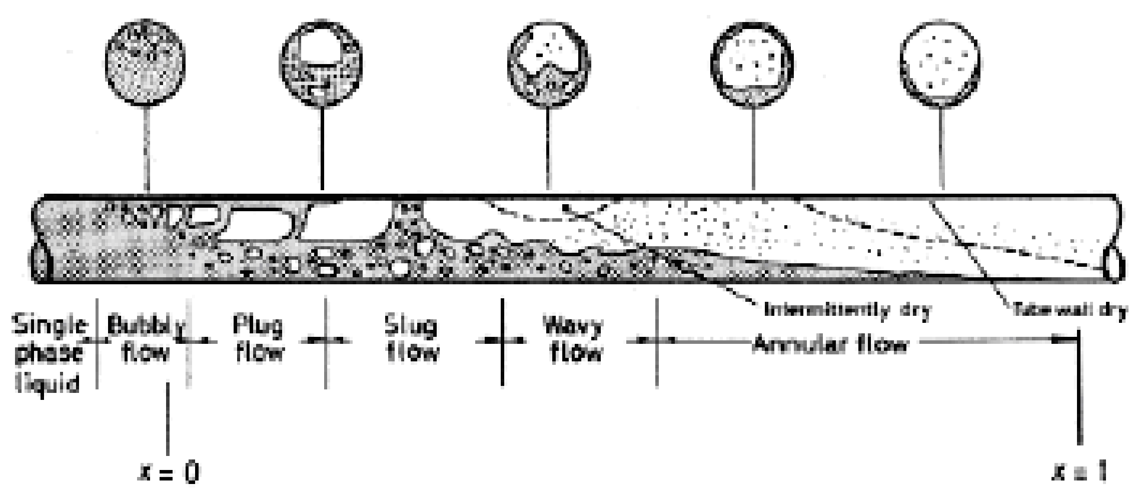

Fig. 3 - Illustration of two-phase flow patterns occurring in horizontal evaporator tube

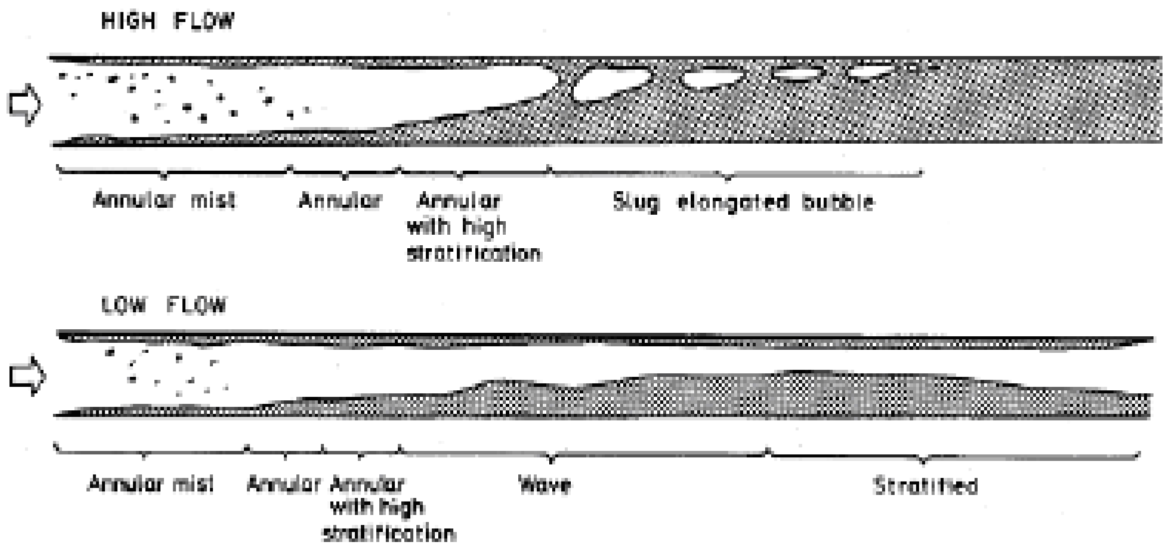

Fig. 4 - Illustration of two-phase flow patterns occurring in horizontal condenser tubes

Normally, saturated, dry, steam is recommended for heating of fluids in a bath using an immersion heat exchanger. This ideal situation is not often realized, due to the long run of steam from the boiler, and more often than not, the steam is wet (i.e., has some condensate). Multiple points of use and purpose of the steam, un- or under insulated lengths of steam pipe, make it difficult to assure perfectly dry, saturated steam and some boilers generate slightly superheated steam to compensate for the in-transit heat loss.

Temperature Driving Force, ΔT

The delta T (ΔT) of equation 2 is an average of the temperature difference between the hot and cold fluids, and is a key determinant of the rate of heat flow. ΔT is the driving force for heat transfer from the hot zone to the cold zone, and can be visualized as being equivalent to the potential difference for current flow (electrical) or mass flow (gravitational). The actual temperature difference varies with location along the heat flow path, and the mean ΔT is calculated as the log mean or the arithmetic mean of the temperature difference profile from the inlet end to the outlet end of the heat exchanger.

Surface Area, A

The purpose of any heat exchanger design calculation is to arrive at a surface area, A, (in Equation 2). A larger area provides a larger rate of heat transfer. Numerous attempts, some partly successful, have been made to increase the surface area within a given space or volume. Success has been thwarted in many cases, in real life, due to a number of reasons, for example – flow is impeded due to tight spaces between the coil surfaces or increased sludge deposit due to higher surface availability.

Materials and Construction of Fluoropolymer Immersion Heat Exchangers

Fluoropolymers such as FEP, PFA, PVDF and, in some cases, PTFE are used as tubing materials in Immersion heat exchangers. The choice of material among these options is based on conditions such as operating temperature, tubing pressure, abrasive environment with suspended solids in the bath, solids or sludge concentration and stickiness (phosphate salts are notoriously sticky !). It is important to recognize the difference in properties of these plastics during the materials selection process. A comparison of properties of these materials is available at the following link: https://www.fluorotherm.com/technical-information/materials-overview/material-comparison/. Specifically, the tensile strength (which determines burst pressure) at the temperature of use and the upper use temperature (which generally determines longevity) must be factored in the choice of material. (See also pressure rating notes at the link: https://www.fluorotherm.com/technical-information/tubing-pressure-specifications/.

The tubing is wound up as a coil, and several coils are supported in a frame that is constructed of PTFE, steel rods encased in a PTFE jacket, PVDF, Polypropylene or other corrosion resistant materials. Several of these frame materials can be combined into a single frame. The choice of material in a support frame is based on the application environment, specifically temperature and the chemical used. Figures 4, 5 and 6. shows some examples of frames.

FLUOROTHERM POLYMERS INC.
www.fluorotherm.com
sales@fluorotherm.com

THERMORON® HEAT EXCHANGERS

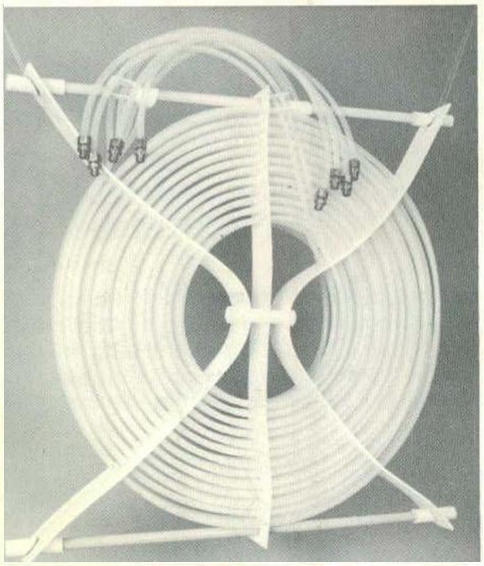

Fig 6. Standard PTFE Frame Heat Exchanger

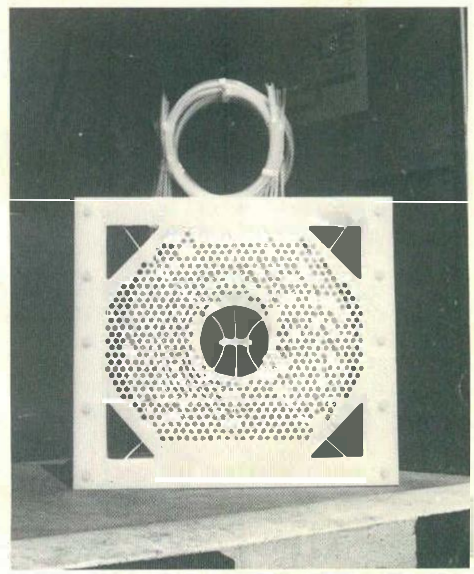

Fig 7. Exchanger within Polypropylene protection frame, Perforated

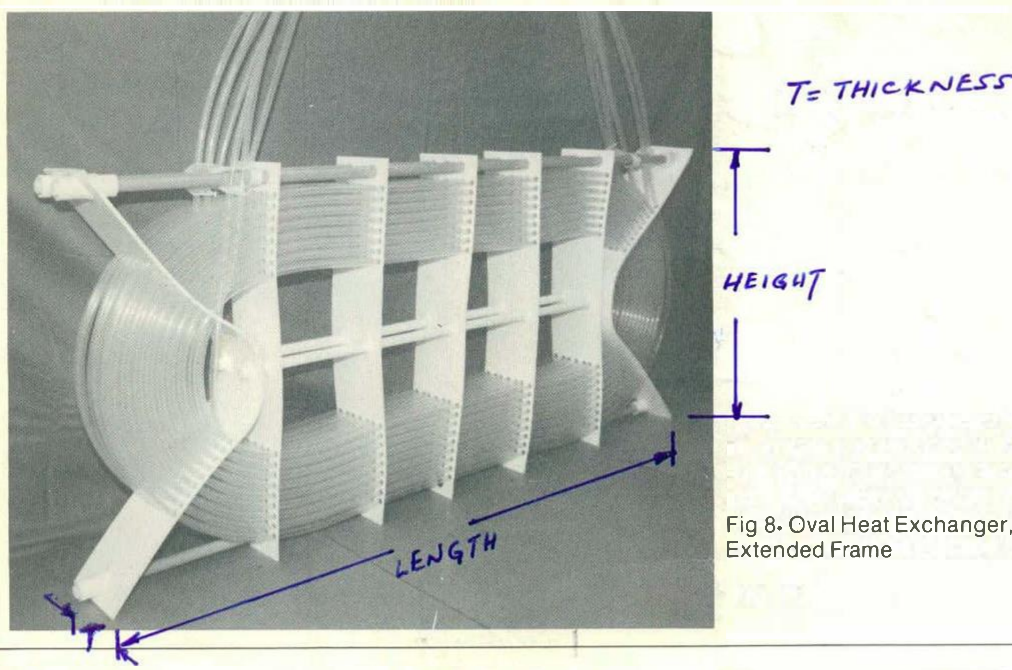

Fig 8. Oval Heat Exchanger, Extended Frame

Figs, 5,6 and 7 - PTFE and Polypropylene Frame Immersion Heat Exchangers

Mounting, Installation and Operation of Immersion Heat Exchangers

Immersion Heat Exchangers are installed inside process tanks and at either one or both ends of a tank, or placed on the wall along the length of the tank. The location is decided by the space available (for existing tanks) and by the need to avoid hot spots, the latter minimized by agitation, if necessary. For tanks that have frequent batch loads, for example in pickling (acid cleaning) where steel or another metal is dipped into the acid, the agitation provided by this action is normally sufficient to ensure reasonable mixing and temperature uniformity. In truly continuous processes, both the acid (injected through nozzles) and the metal load are in continuous motion and no agitation is required.

An example of a heat exchanger installed in an acid tank with agitation, is shown in Figure 8 below –

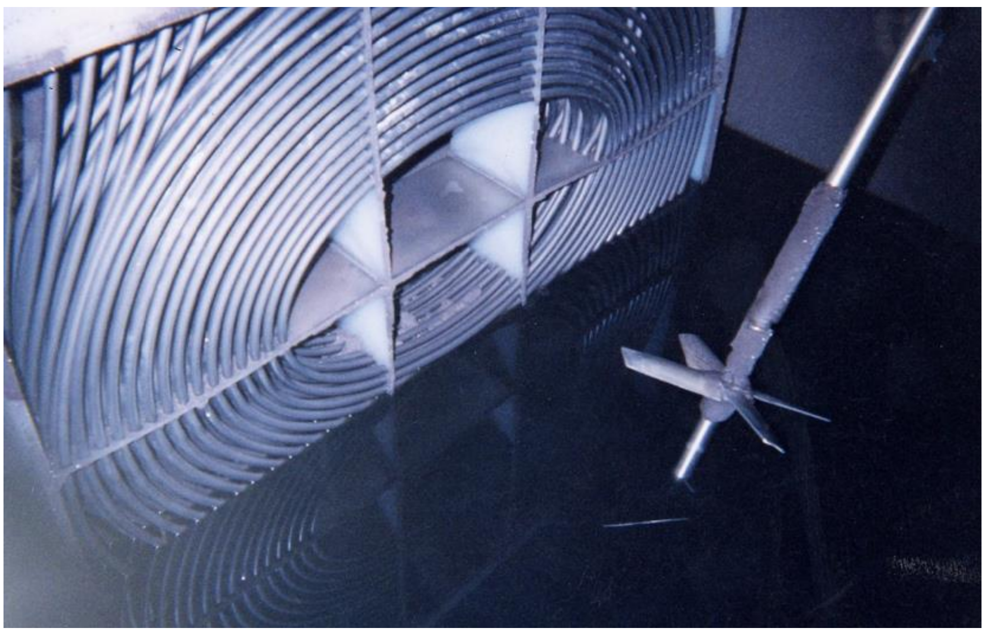

Fig. 8 – Fluorotherm® Heat Exchanger in Acid Tank with Agitation

Where space is limiting inside a tank, an external installation consisting of Immersion heat exchangers installed in a self-contained tank may be used. The heating or cooling is accomplished in this unitized assembly. This is a closed loop system and process fluid flows out of and back into the process tank through the heat exchanger tank. Continuous filters may be installed in this loop to remove sludge (oxides, salts) in the process fluid. Depending upon the heat load and the size of the process tank, external heat transfer units are advantageous in that any preventive, shutdown or emergency maintenance required can be performed off-line, the tank does not have to drained and the production process need not be shut down. Some immersion heat exchanger designs offer the advantage of in-situ repairs, in case of tube coil damage or leaks, so that a production shut down is avoided.

Size Range of Heat Exchangers

Fluoropolymer Immersion Heat Exchangers are available in a wide range of sizes – from 1 sq ft (0.1 sq. meters) or less to 350 sq. ft (32 sq. meters) or more. The smaller sizes (mini-heat exchangers) are generally used for small baths, for example in plating, medical, pharmaceutical fluids temperature control, and semiconductor processing. Larger sizes are used in heavy industry – steel, mining, aerospace, galvanizing, chemicals processing, paper and the oil industries, to name a few.

Key Factors to Consider in the Selection of Immersion Heat Exchangers

Your investment in heat exchangers can be significant - not just the purchase price but also the cost of maintenance and repairs (whether in-house or out sourced), replacements, spare parts, and perhaps most importantly, the cost of production downtime. These issues, along with the expected use life, must be considered when making a purchase decision.

Fluoropolymer heat exchangers compete against exotic metal alloys and among themselves (variations in design and materials), in the industrial market where harsh chemicals must be temperature controlled. There is little such competition in the ultra-pure space, such as semiconductors, where contamination is the prime concern (fluoropolymers are non-contaminating due to chemical inertness). Answers to the items and comments listed below, especially on design and performance factors, should be included in your decision –

1. Will it fit into my existing tank?
2. How long will it last?
3. Space between tubing rows or coils - sometimes the coils are randomly packed and stuffed inside the frame or box, or the tubes bundled up tightly
4. Do the coils get plugged (fouling) – this impedes the free flow required for heat transfer, and creates hot spots?
5. If fouling occurs and sludge sticks to tubes, do I really have a heat exchanger performing according to design?
6. Does performance get worse with time, how soon does it start to decrease – will my bath heat or cool slowly over time? What effect will this have on my production?
7. Does the manufacturer produce to specifications, and have complete quality control over key product components?
8. Can I easily clean the heat exchangers of solids with a steam or hot water spray or jet, without damaging the coils?
9. If there is a tube breakage, do I have to repair by welding (perhaps outsourced, if a specialty alloy) or discard the heat exchanger (graphite blocks, for example)
10. Can I quickly repair, isolate or disable a damaged coil or tube, and get back online?
11. How does the chemical resistance compare within my choices of materials and designs?
12. What is the total ownership cost, the up-front purchase price plus maintenance and downtime.

The foregoing points must be carefully evaluated to help arrive at the best decision.

Summary
The theoretical basis of performance of immersion heat exchangers is well established. Thermal conductivity of the heat exchanger material, flow, thermal driving force (a mean temperature difference between the service and process fluids), particulates in the bath, and whether the production process is batch or continuous are some of the important process considerations. The maximum available surface area for heat transfer varies with the manufacturer's design, material and geometry of the product. The choice of the heat exchanger should take into account the factors listed in the foregoing paragraph, and the consequences of a good selection can keep the cost of repair, replacement, delay and shutdown at bay.

Prabhat N. Shukla, Ph.D.
Fluorotherm Polymers Inc.

References:

Figure 1. Fluorotherm Polymers Inc. – Example of Immersion Heat Exchanger
Figure 2. Diagram from Wikipedia, Keyword - Thermal Resistance
Figure 3. Heat Transfer Databook_iii_1.pdf, Author John R. Thome, Faculty of Engineering Science and Technology, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland
Figure 4. Heat Transfer Databook_iii_1.pdf, Author John R. Thome, Faculty of Engineering Science and Technology, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland
Figure 5,6 and 7. Fluorotherm Polymers Inc. – Immersion Heat Exchanger frames
Figure 8. Fluorotherm Polymers Inc. – Immersion Cooling Heat Exchanger in acid bath

The information, recommendations, and data have been sourced from published information or from Fluorotherm Polymers Inc., archives, and provided in good faith. The author or Fluorotherm does not assume responsibility, expressed or implied, as to its accuracy and completeness. It is the responsibility of the consumer to verify the content and evaluate its suitability for their application. Fluorotherm does not make any claims and does not provide any warranties for their product based on this article.

Fluorotherm® is a registered Trademark of Fluorotherm Polymers Inc.
Hastelloy™ is a Trademark of Haynes International, Inc.