



## The Use of Air Cooled Heat Exchangers in Mechanical Seal Piping Plans

**Kyle Snyder**

Staff Engineer

Flowserve Corporation - Seals

Temecula, CA, United States



*Kyle R. Snyder is a Staff Engineer in the Flow Solutions Division of Flowserve Corporation, in Temecula, California. He joined Flowserve in 2011 as an Applied Technical Solutions Engineer supporting mechanical seals in the Texas Gulf Coast region. Kyle received his B.S degree in Mechanical Engineering from Western New England University and his Master's*

*degree in Aerospace Engineering from the University of California, Los Angeles.*

### ABSTRACT

Piping plans provide a formalized approach to enhancing the environment of the mechanical seal. One of the most frequent methods of modifying the seal environment is to reduce the temperature of fluids in the sealing systems. This has the effect of increasing viscosity, reducing vapor pressures, and removing seal generated heat.

Not all seal applications have a viable water source to apply a water cooled exchanger. In place, air cooled exchangers provide a low cost, low maintenance solution for mechanical seal piping plans. Natural and forced convection coolers can prove very effective but require several considerations including material selection and environmental conditions. Properly selecting and sizing the coolers can contribute to the success of a mechanical seal.

### AIR COOLED HEAT EXCHANGERS

#### *Natural Convection vs Forced Convection*

Most air finned coolers are commonly supplied as natural convection. This means there is no external means of providing air flow over the cooler. Natural convection works on the principle of buoyance. As air near a hot surface becomes less dense, it rises and is displaced by cooler, denser air. This continual exchange of fluid results in convective heat transfer. Natural convection is highly dependent on the surface temperature of the fin and tubing. The hotter the surface, the less dense the air gets and convection can occur at a higher rate resulting in more heat removal. This is why air finned exchangers can be effective in high temperature applications where water coolers may be limited due to vaporization or fouling on the coolant side.

Buoyancy is a function of earth's gravity. Natural

convection occurs on any geometry as long as a temperature differential occurs between the fin and ambient air. The gravitational component is that acting normal to the cooling surface. Optimal performance would occur when the plate is vertical however this affects the size and required space of the exchanger. Fin and cooler orientation may have a special orientation to manage both cooler size and performance. Refer to the coolers manufacturers' installation instructions to ensure optimum performance.

Forced convection provides a more effective means of heat removal over natural convection. Air is driven over a bank of finned tubing typically provided by a fan. The air's high velocity over the fins is capable of removing thermal energy at a higher rate as hot air is continually removed. Performance of a forced convection exchanger can also be enhanced by the fan design. Several variables can be considered when applying a fan including increased rotational speed, the number of blades, blade pitch and shrouding. Unlike natural convection exchangers that may require a specific orientation, forced draft coolers can be mounted anywhere. The air velocity should be orientated parallel with the fin geometry. This provides high velocity across both surfaces of the fin without obstruction. Figure 1 is a shrouded fan that is directing flow parallel to the fin orientation for the most efficient cooling.



*Figure 1. Forced Convection Air Fin Cooler*

#### *Environmental Considerations*

Air cooler performance is influenced by site conditions. Ambient air temperature has a big impact but there are other considerations when applying air coolers. Altitude and weather not only affect the cooling capability of air, but may also dictate what materials are selected for the exchanger. Moisture

in the atmosphere may produce rusting or fouling on fins and tubing of the exchanger. Material selection and fin attachment methods should be considered based on weather conditions if applied outdoors. Oxidation of the fins can act as an insulator and decrease the performance of the exchanger considerably.

Convection from these units, especially natural convection, could be influenced by radiation from surrounding equipment or solar radiation. Figure 2 is an example of a natural convection exchanger mounted outdoors. Above is a solar cover to prevent exposure of the exchanger to direct sunlight. The cover contains slats to allow hot air to escape and is also mounted well above the exchanger to provide adequate air flow near the exchanger. This inhibits solar energy but does not restrict convection from the exchanger.



Figure 2. Natural Convection Air Cooler with a Solar Shade

This energy acts as a heat input into the seal cooler and may reduce its performance. This is applicable when air coolers are applied indoors or outdoors.

When applied in remote locations with minimal maintenance, careful consideration of environment consideration should be taken. Low ambient temperatures can negatively affect the seal system if the fluid is not properly selected for a barrier or buffer system. Viscosity may become too high making a mechanical seal prone to blistering or even freezing. Wide ambient temperature swings may also cause a large variation in fluid viscosity. The change in viscosity may affect the seals dynamic lubrication which may contribute to leakage variation. Ensure the fluid and selected cooler are correctly applied given the conditions.

### Fin Design

The effectiveness of an annular fin is dependent on a number of variables. The geometry of the fin itself dictates cooling area and conductive path through the fin. Convective coefficients of the surrounding environment affect the performance of the fin. These variables are taken into consideration when initially designing the exchanger and later evaluating its performance. Together these variables define the fin efficiency of a specific design.

The surface area of the fin is directly related to the amount of heat the fin is capable of dissipating however there are limitations. The highest temperature of the fin will be closest to the tubing and heat is conducted radially outward towards the tip of the fin. The temperature profile of the fin is dependent on the fin material and geometry. Higher conductivity fin material will allow a more uniform temperature distribution on the fin. Conductive heat transfer through the fin is dependent on the inner and outer diameter of the annular fin as well as the thickness. These three geometric features affect how well the fin conducts heat (Incropera 2007).

Convective heat transfer occurs from the fin to the atmospheric surroundings. The effectiveness of this is a function of exposed surface area, ambient air conditions and temperature differential. The temperature gradient of the fin decreases radially outward from the center of the annular fin. The radial temperature profile of the fin creates a varying differential between it and the surrounding air. A large fin composed of a low conductivity material will have a large temperature difference between the inner radius and the outer radius. The temperature differential at the outer radius of the annular fin will not be as effective in removing heat because it is at a lower temperature differential with the ambient air. A smaller fin made of a material with a high thermal conductivity will have a more uniform temperature distribution. This high temperature differential across a larger surface results in a much more effective fin design. A well designed fin arrangement requires a balanced design of performance, size and cost.

For example, take an annular fin with an inner radius of 1 inch (25.4 mm), outer radius of 2.75 inch (69.85 mm) and a thickness of 0.032 inch (0.8128 mm). It has a prescribed temperature at the inner radius of 212°F (100°C). Figure 3 are the resulting temperature profiles for fins constructed of copper, aluminum and steel. The high conductivity of copper provides a high temperature differential on the entire fin. Based on that observation, a copper fin could be a larger size and still be highly efficient and increase the overall surface area of the exchanger. A steel fin however has much lower fin efficiency and consideration must be taken when considering the size of the fin as that directly affects the cost of the exchanger.

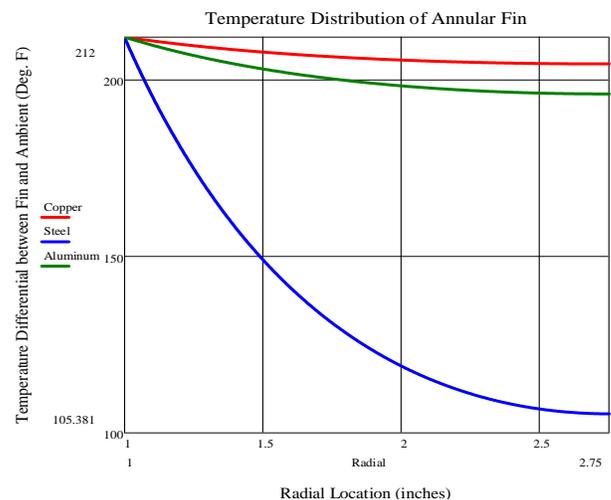


Figure 3. Radial Temperature Profile of an Annular Fin Composed of Various Materials

The lower temperature differential towards the tip of the fin is an area of low heat transfer due to the small temperature differential. A large fin has increased surface area but the result is a minimal amount of convection occurring towards the outer diameter of the fin. Figure 4 illustrates a temperature profile on a forced draft cooler with the fan mounted below. The leading edge of the fin is much cooler than the back edge of the fin. The tip of the fins is also at a cooler temperature than the base attached to the tubing. Fin efficiency is an important parameter when designing and evaluating fin arrays. Evaluating the efficiency and material required to effectively remove a heat load can lead to significant savings when it comes to material costs and size of the exchanger.

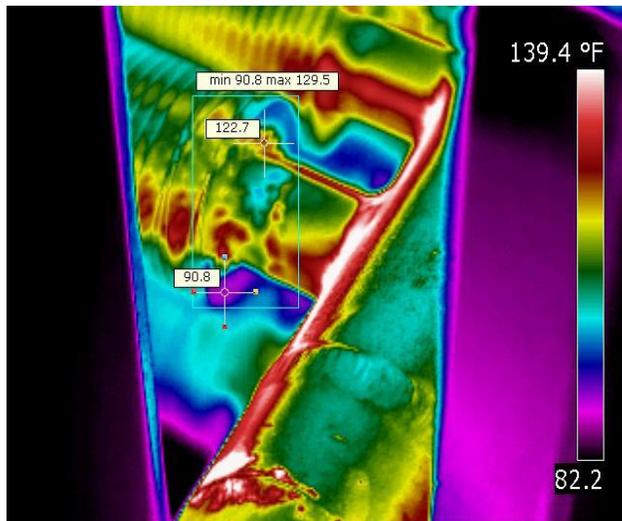


Figure 4. Thermal Image of a Forced Convection Cooler with Fan at the Bottom

#### Installation Methods

Air cooled exchangers are constructed of a smooth tubing with annular fins attached to the outer diameter of the tube. How the fins are attached depend on design and application. Common attachment methods include tension wound fins, embedded fins, 'L' wrapped fins, double 'L' wrapped fins. Figure 5 shows two cross sections of spiral wound and 'L' wrapped fins.

Tension wound fins are tightly wrapped around the exterior of the tube and are either welded or stapled in place. Embedded fins are inserted into a groove in the tubing or pressed into the material and welded in place. These two methods can be applied in high temperature application conditions and offer excellent thermal efficiency.

'L' wrapped fins have the cross section of an L which provides a footing and increased contact region between the tube and the fin. The 'L' fin design is applied in temperatures up to 350°F and offers maximum heat transfer at lower temperatures. The fin is formed into an L shape and tension wrapped around the tube. The foot of the fin mates against the adjacent fin completely covering the base of the tube providing resistance to atmospheric corrosion. Double 'L' wrapped fins are interlocking which prevent movement or separation. They

offer higher corrosion and wider temperature range since the fin overlaps the previous fin and allows more tube coverage.

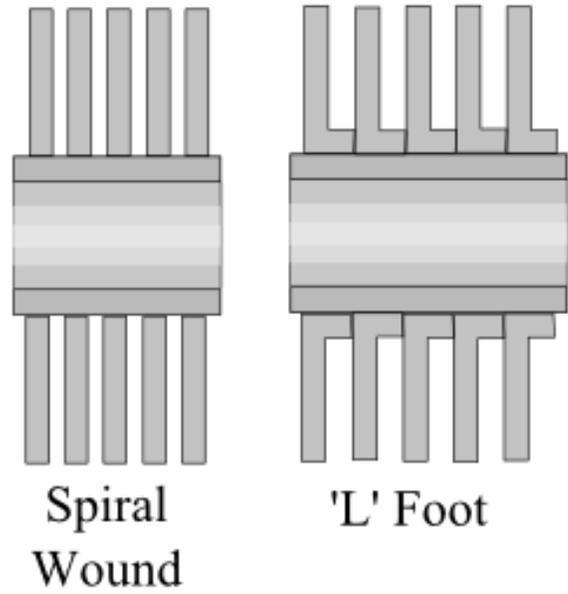


Figure 5. Different Fin Attachment Methods

Each of these attachment methods has advantages and disadvantages but all introduce some amount of thermal resistance to the system. The most efficient design would be machined fins so there is no contact interface between the tube and fins however this is not often applicable in seal coolers. The contact resistance is a result of voids between the two materials forming air pockets and reducing surface contact area. The attachment method to the tubing may also have a lower thermal conductivity than the fin or tubing which inhibits heat transfer between the tubing to the fin. When care is taken in manufacturing of the fin array, the contact resistance is negligible when evaluating exchanger performance.

Tubing and piping size ranges from ½ inch to 1 inch for applications on mechanical seals. The material is typically 316 or 316L but could vary depending on the application to other alloys including duplex or monel. Fin materials are commonly aluminum, carbon brazed or stainless steel copper.

#### Fouling

Fouling is defined as the deposition of an insulating layer of material onto a heat transfer surface. This can occur on either the process side or atmospheric side of air cooled heat exchangers. Fins can become contaminated with dust or debris that may be in the surrounding area. Environmental conditions may deposit a layer of material on the fins and tubing which may act as an insulator and decrease the overall performance of the exchanger. In mechanical sealing applications, air cooled exchangers are applied within buildings and also in remote locations that may be exposed to the elements. The added benefit of air cooled exchangers in remote locations is that they require minimal maintenance on the coolant side of the exchanger. Over time fouling may begin to inhibit performance of the exchanger.

Tube fouling is a consideration in some mechanical seal applications. An exchanger installed in a pressurized barrier system, such as a plan 53 or 54, will contain clean barrier fluid that generally does not lead to fouling of the tubing. Tube fouling is more of a concern when cooling contaminated process in a plan 21 or 52 application that may see process fluid in the buffer system. Some applications of air cooled exchangers cool plan 32 headers from a high temperature source. Fouling is more likely to occur at elevated temperatures and may be a concern in plan 32 cooling.

#### Air Cooled versus Water Cooled

Water is a superior coolant to air when it comes to efficiency. However, not all seal applications are suitable for water coolers or are located in remote locations where cooling water is not available. Natural draft air exchangers may be applied in moderate to high temperature applications ranging from 250-750°F (121-399°C) depending on materials of construction. The higher temperature provides higher convective rates and a larger temperature differential, removing more heat. In cooler to moderate sealing applications, ranging from 100-250°F (37-121°C), the temperature differential may not be enough to remove the proper heat load on the system or be effective. In these cases, forced convection or water coolers may be considered to remove the required heat by increasing the convective rates with a fan or increasing the specific heat of the coolant. Cooling water has a much higher specific heat, which improves its ability to remove heat. In general, natural convection exchangers can remove a few hundred to a few thousand BTUs/hr. Forced convection exchangers are much more effective with the ability to remove a few thousand to tens of thousands of BTUs/hr. The amount however depends on the exchanger design and application conditions.

Moderate to high temperature applications improve the efficiency of air exchangers driving a higher temperature differential between the exchanger and ambient conditions. It is important to consider how the exchanger will be used in the system and the required cooling for the seal. High temperature applications may have the potential for vaporizing water as a coolant if not properly maintained. This increases the potential for damage to the exchanger or fouling. The various API piping plans all have different cooling requirements. Evaluating the predicted heat load ensures the cooler is properly sized and selected for the application. This evaluation can determine the use of a natural convection, forced draft or water cooler. Selection and sizing is generally completed by the OEM as the coolers capabilities are dependent on design considerations previously discussed.

#### Piping Plans

Air exchangers can be utilized in a variety of piping plans. Evaluating the heat load for these exchangers is dependent on how they are being utilized. Piping plans that continually cool a stream of fluid, such as a plan 21, only require removing heat from the process stream.

$$Q_{Exchanger} = 500 * GPM * C_p * SG * (T_{in} - T_{out})$$

Other piping plans that operate in a closed system may have the addition of heat soak and seal generated heat to remove from the seal system. These heat loads can be significantly high in high temperature applications.

$$Q_{Exchanger} = Q_{Heat\ Soak} + Q_{Seal\ Generated\ Heat}$$

Evaluating the required heat removal for the exchanger at given operating conditions can determine if an air cooled exchanger would be suitable for the application. The heat load may be too high for an air cooled exchanger to maintain a good environment for the seal.

The primary goal of implementing any piping plan is to improve the sealing environment which includes maintaining manageable temperatures on the seal. Metals and elastomers must be properly selected for the sealing fluid temperature to avoid compromising the performance. Indirectly affecting the seal is how temperature varies fluid properties. Viscosity and vapor pressure are important considerations when selecting and applying seals. Air exchangers utilized in auxiliary systems can greatly improve sealing environments and reliability.

API Plan 21

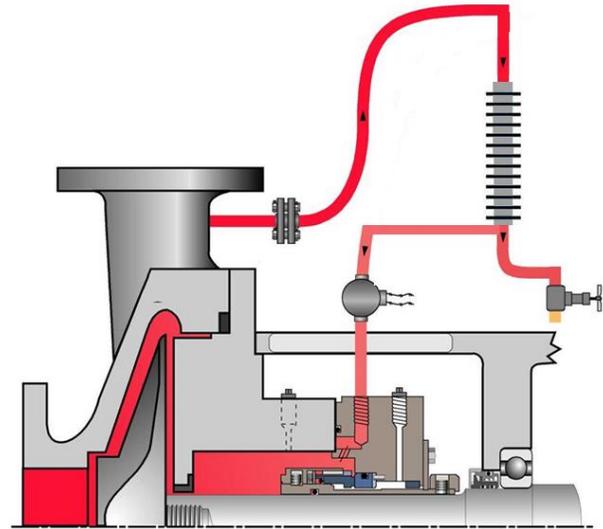


Figure 6. API Plan 21 Piping Arrangement

API plan 21 utilizes a flush line pulled from the pumps discharge back to the seal chamber. Flow is generated by the pressure differential and managed commonly with an orifice in line. A heat exchanger piped inline cools the flush fluid to provide an improved seal environment and lubrication for the faces. Keeping the seal cool also helps manage thermal distortions that may be present in high temperature applications.

### API Plan 23

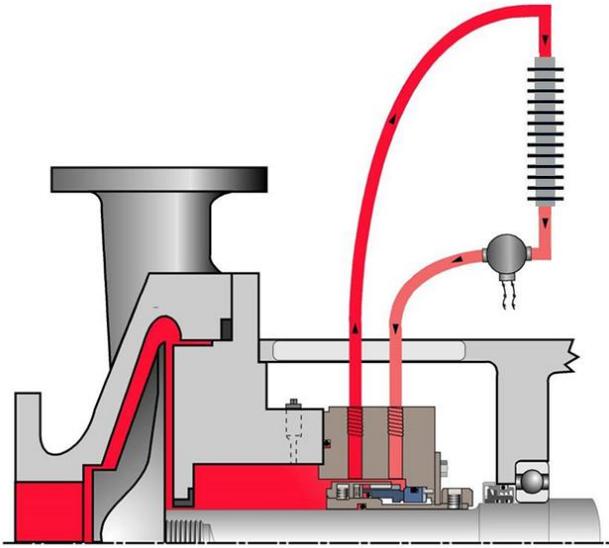


Figure 7. API Plan 23 Piping Arrangement

A plan 23 continually cools the seal chamber process fluid. To isolate the seal, a close clearance bushing is commonly used in the box bore to isolate the hot process and the plan 23 loop. There is minimal fluid exchange between the plan 23 and the process fluid because there is minimal pressure differential driving flow. Any fluid exchange will be driven by thermal gradients causing convection and mixing. The exchanger in a plan 23 must remove the seal generated heat and heat soak from the hot equipment at equilibrium conditions.

### API Plan 32

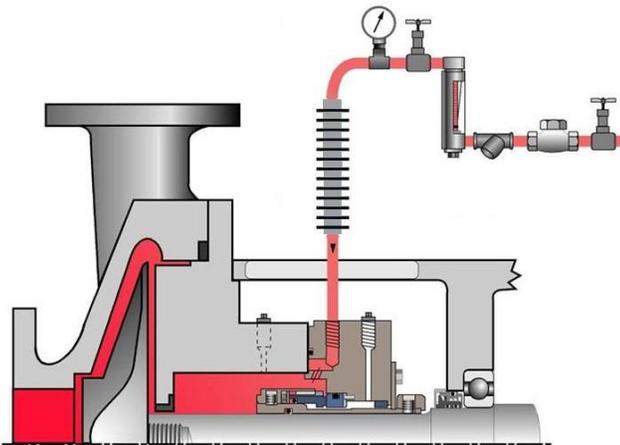


Figure 8. API Plan 32 Piping Arrangement

API plan 32 is used to provide a cool, clean fluid from a high-pressure source to improve seal operation. Similar to the plan 21 except the plan 32 is a different fluid than what is being pumped. There is typically a bushing at the bottom of the equipment to maintain flow and isolation between the flush fluid and the process. Hot flush fluids can be cooled in a plan 32 providing the added benefits of cooling the mechanical seal environment.

### API Plan 41

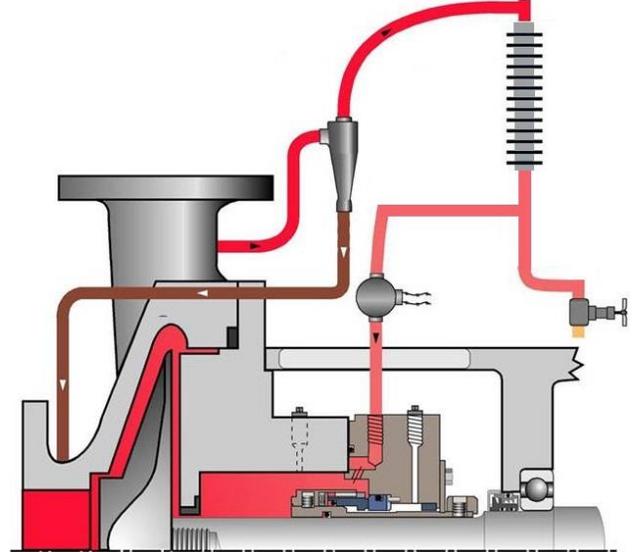


Figure 9. API Plan 41 Piping Arrangement

A plan 41 is similar to a plan 21 with the exception of a cyclone separator is utilized upstream of the exchanger. This is applied in applications where solids in the flush may be a concern. The cyclone separator will split the flush flow into two streams. The dirty stream will be routed back to the suction line and the clean flush will be cooled through the exchanger back to the seal. The split flow will result in a lower flush flow for the seal and a larger temperature differential across the air cooled exchanger.

### API Plan 52

The API plan 52 is utilized on dual unpressurized seals. The seal pot containing the barrier fluid may have cooling coils in the seal pot or a seal cooler may be piped in line with the reservoir. The flow is generated by the pumping action of the seal. Seal generated heat and heat soak into the buffer fluid are removed by the exchanger. Piped in line with a reservoir, the volume of buffer fluid in the seal reservoir provides additional cooling. Increasing the volume increases the heat capacity of the buffer/barrier which contributes to maintaining cooler temperatures on the system.

## API Plan 53

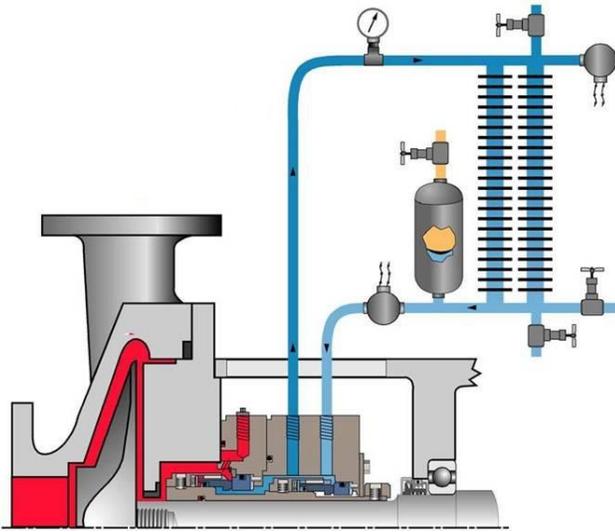


Figure 10. API Plan 53 Piping Arrangement

The cooling requirements of an API 53 are the same as the plan 52 except the system is pressurized. Cooling requirements on the system are the same.

## API Plan 54

An API plan 54 is pressurized and utilizes an external circulation pump to provide flow on the barrier system. The circulating pump enhances heat removal on a plan 54 as it provides more flow than what would be generated in a typical sealing application.

### U-LMTD Evaluation Methods

In applying coolers to seal applications, it is typically to maintain a certain temperature that is compatible with the sealing components and moderates the fluid properties to provide a good sealing environment. These properties include vapor pressure, viscosity and density that effect sealing performance. There are several ways to evaluate these exchangers to estimate what the system temperatures of a given piping plan will be.

The U-LMTD method is a well-recognized evaluation method for seal coolers. The overall heat transfer coefficient, U, is defined as the resistance of heat transfer between the hot and cold fluid. This value accounts for the internal convection of the fluid being cooled, conduction through the tubing, convection to the atmosphere and potential fouling that may occur. The total surface area of the exchanger is defined as A. The 'UA' value is the convective coefficient associated with the overall cooling area of the exchanger. The heat transfer coefficient can be calculated theoretically. The convective coefficient, h, is applicable to both the tube and air side of the exchanger. There are many correlations that exist for tube flow that are a function of tube size, internal velocity and fluid properties. Correlations for finned tube tanks predicted convective coefficients externally based on velocity, fin

geometry and spacing. For best performance, the tubing should be a high conductivity material and thin so heat can easily be removed from the fluid to the fins. In most cases this term is negligible. In high pressure or corrosive applications, special tubing material may be required for the extreme conditions. The thermal conductivity of these materials may have a significant impact on the exchanger performance and conduction through the tubing needs to be evaluated (Incropera 2007). The surface area, A, is the exposed tubing internally and the exposed area externally including the surface area of the fins. The fouling factor terms account for degrading performance of the exchanger after extended use. API 682 4<sup>th</sup> edition now specifies fouling factors for the atmospheric cooling side that can be utilized in evaluating exchanger performance.

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{R_{f,i}^*}{A_i} + \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi k L} + \frac{R_{f,o}^*}{A_o} + \frac{1}{h_o A_o}$$

The "UA" value is required to evaluate outlet temperatures of the exchanger when inlet temperatures are known. For instance a plan 21 energy balance would be as follows.

$$UA(LMTD) = 500 * GPM * C_p * SG * (T_{in} - T_{out})$$

The right hand side of the equation is the energy removed from the hot fluid based on flow rate and fluid properties. This is applicable to either the process side or the air side of the exchanger as the heat removal from those to streams must be equal.

$$Q_{Seal Flush} = Q_{Air}$$

The log mean temperature difference is defined based on the flow configuration being parallel or counter flow. In either case, it is a function of both the inlet and outlet temperature of the process and air.

The energy balance on a closed loop system, such as a plan 23 or 53, would be

$$UA(LMTD) = Q_{Heat Soak} + Q_{Seal Generated Heat}$$

The solution process to evaluate the exchanger performance on a close loop system is more rigorous and requires iteration. The overall heat transfer coefficient may be known however the inlet temperature is depended on equilibrium operation. Both the log mean temperature and the heat soak are dependent on the seal cavity temperature. Iteration for the inlet and outlet temperatures is required until the energy equation is balanced.

### Installation Process and Piping Practice

- The inlet to the cooler should be at the top and the outlet at the bottom. This promotes thermo-syphoning in standby conditions as the dense fluid falls to the bottom and the hot fluid rises creating a small amount of circulation in the system.
- Piping should have smooth curves to and from the

seal. This is especially important in auxiliary systems where the rotation of the seal generates the flow through the exchanger. Reducing the amount of turns and fittings in the piping decreases the losses in the system making the pumping feature more efficient.

- Locate a high point vent on the process side to remove any trapped vapor. Without doing so the cooler performance may reduce or the system may become vapor locked.
- Take note on whether the exchanger requires a specific orientation. Some require a specific mounting to optimize heat removal.
- Placing the exchanger directly in the sunlight may reduce performance as radiation energy is an input into the exchanger.

#### *API 682 4<sup>th</sup> Edition Requirements*

API 684 4<sup>th</sup> edition includes a designated section for air coolers. Previously, air coolers were incorporated into various piping plans in the 3<sup>rd</sup> edition. The increasing use and application of the air coolers warrants a section dedicated to their use. The minimum piping requirements for auxiliary tubing apply to air cooler designs. Specifics for air coolers include the following:

- Air coolers shall be constructed with finned tubing arrangements with seal flush fluid on the tube side. Unless otherwise specified, coolers shall be natural draft.
- Forced draft coolers shall be applied and engineering on agreement between the purchaser and seal vendor.
- Tubing shall be composed of austenitic stainless steel type 316, 316L or 316Ti. Fins are to be composed of aluminum or stainless steel fixed with a suitable bonding method. Austenitic stainless steel type 316L or 316Ti shall be used if connections or tube-header connections are welded
- Air cooler design shall be arranged for complete draining and venting on the tube side.
- Unless otherwise specified the design of the air cooler shall include a fouling factor 0.0006 hr-ft<sup>2</sup>-°F/Btu to 0.0023 hr-ft<sup>2</sup>-°F/Btu (0.1-0.4 m<sup>2</sup>-K/kW)

For further specifics refer to API 682 4<sup>th</sup> edition.

#### **CONCLUSIONS**

There are many items to consider when it comes to sizing and designing air cooled exchangers. Fin design is critical to the coolers performance as well as keeping costs to a minimum. Fin efficiency needs to be optimized to reduce the amount material require yet provide ample cooling for the application. In addition to fin design, environmental conditions influence both performance and may dictate material selection. Environmental consideration prevents fouling of the exchanger which may inhibit long term performance. All these variables are taken into consideration when applying an air cooled exchanger. API piping plans are utilized to improve seal

environments, reliability and performance of mechanical seals.

#### **NOMENCLATURE**

h	= Convective Coefficient
A	= Surface Area
R <sub>f</sub>	= Fouling Factor
D	= Diameter
k	= Thermal Conductivity
L	= Length
U	= Overall Heat Transfer Coefficient
GPM	= Gallons Per Minute
C <sub>p</sub>	= Specific Heat
SG	= Specific Gravity
T	= Temperature

#### **REFERENCES**

- API Standard 682, 2004. "Pumps-Shaft Sealing Systems for Centrifugal and Rotary Pumps," Third Edition, American Petroleum Institute, Washington, D.C.
- Incropera, F., Dewitt, D., Bergman, T., Lavine, A., 2007, "Fundamentals of Heat and Mass Transfer," Sixth Edition, John Wiley & Sons, Danvers, MA.

#### **BIBLIOGRAPHY**

- Chen, HT., Chou, JC., Wang, HC. 2007, "Estimation of heat transfer coefficient on the vertical plate fin of finned-tube heat exchanger for various air speeds and fin spacings.", International Journal of Heat and Mass Transfer, 50, pp.45-57
- Perrotin, T., Clodic, D., 2003, "Fin Efficiency Calculation in Enhanced Fin-And-Tube Heat Exchangers in Dry Conditions.", International Congress of Refrigeration, Washington, D.C.
- Wilcox, D., 2010 "Basic Fluid Mechanics," Forth Edition, DCW Industries, La Canada, California.

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