COLMAC COIL
Manufacturing Inc.

Technical Bulletin

By Bruce I. Nelson, P.E., President, Colmac Coil Manufacturing, Inc.

COMPARING AMMONIA EVAPORATOR CONSTRUCTION: "WHICH ONE IS BEST?"

Abstract

Industrial ammonia evaporator manufacturers offer several types of construction including: galvanized steel, stainless steel tubes with aluminum fins, stainless steel tubes with stainless steel fins, and aluminum tubes with aluminum fins, as well as a number of corrosion resistant coatings. Trying to decide on the right one for a given facility and/or process can be confusing and leads to the question: "Which one is best for my application?" The metals used in each type of construction mentioned above have unique properties which affect the evaporator in terms of thermal performance, weight, defrost energy, corrosion resistance, and cost. Good performance and energy efficiency have a direct positive effect on return on investment for the facility. The weight of the evaporators may affect the roof structure of the building in the case of ceiling or roof mounted units, especially in high seismic zones. In food processing plants where harsh cleaning chemicals are increasingly used on evaporators, appropriate corrosion resistance behavior is critical. The article examines the different types of construction and their characteristics and makes recommendations regarding which type of construction best suits specific applications and operating environments.

Background

Air-cooling evaporators ("air coolers") used in ammonia systems have traditionally been made using galvanized (zinc coated) carbon steel. There are other metals which exhibit excellent compatibility with ammonia, including stainless steel and aluminum.

Designers and installers of industrial ammonia evaporators must be concerned with the cost, weight, performance, and reliability of the equipment being specified. Additionally, there may be requirements for corrosion resistance, cleanability, and defrosting characteristics, which need to be considered.

Aluminum is a good choice for both tubes and fins. The surface of the metal is naturally passivated (the protective oxide layer is stabilized) when directly exposed to ammonia, leading to its widespread use for ammonia-containing vessels, pipe, and tubing. The properties of aluminum also make it an ideal metal to use as fin material. Aluminum is low cost, lightweight, highly conductive, and corrosion resistant.

Some of the properties of stainless steel make it an excellent choice for tubing in ammonia heat exchangers. It has very high tensile strength, which results in high working pressures. Stainless steel is highly corrosion resistant which minimizes the potential for ammonia leaks in hostile environments. It is readily available commercially and is widely used in the food processing industries for piping, vessels, and equipment. It is also easily repaired in the field by welding.

Negative aspects of using stainless steel in heat exchangers are its high relative cost and very low thermal conductivity. These negative characteristics can be mitigated by: a) specifying the wall thickness of the tubing to match the required working pressure of the system, and b) using another more conductive metal, such as aluminum, as the fin material.

Three types of evaporator construction using these metals are in common use and are widely available from a number of manufacturers:

1. Hot Dip Galvanized Steel (Stl/Zn)
2. Stainless Steel Tubes with Aluminum Fins (SST/Al)
3. Aluminum Tubes with Aluminum Fins (Al/Al)

©2016 Colmac Coil Manufacturing, Inc.

Trying to decide which of these metals and types of construction are the best choice for a given application and duty can be confusing. In order to answer the question “Which one is best?”, this article will make a comparison of the following characteristics of each type of construction:

- Strength
- Cost/Price
- Weight
- Performance
- Defrosting
- Corrosion Resistance
- Reliability

Comparison of Properties:

Table 1 below compares several properties of stainless steel and aluminum to those of carbon steel and zinc. Galvanized steel is obtained by dipping carbon steel in a bath of molten zinc, hence these two base metals are shown in the table.

TABLE 1
Properties of Various Metals

Metal	Density, lbm/cu ft	Thermal Conductivity, Btu/sq ft h F ft	Specific Heat Capacity, Btu/lbm F	Tensile Strength, ksi
Carbon Steel	490	26	0.107	47
Zinc	445	65	0.094	21
304L Stainless Steel	501	9.4	0.120	70
3003 Aluminum	165	117	0.215	14

The density of the metal directly affects the weight of the heat exchanger, and when multiplied by the specific heat capacity the product indicates the amount of energy required to heat up and cool down the heat exchanger during a defrost cycle.

The thermal conductivity of the metal affects the thermal performance of the heat exchanger, as well as the speed and effectiveness of defrost.

The tensile strength of the metal will determine the burst pressures of the heat exchanger tubes and headers for a given wall thickness. It is interesting to note that various metals behave differently at low temperatures. Carbon steel becomes brittle at temperatures below –20F. Special allowances must be made when designing with carbon steel below –20F such as using special impact tested material, increasing the wall thickness of the pipe, and post-weld heat treating to avoid failures caused by embrittlement of the metal. Table 2 below shows the normal allowable working temperature range for various metals.

TABLE 2
Normal Allowable Working Temperature Range for Various Metals*

Metal	Allowable Working Temperature Range, F
Carbon Steel (SA-179)	-20 to +500
304L Stainless Steel (SA-249)	-320 to +300
3003 Aluminum (SA-210)	-452 to +400

* Taken from ASME Pressure Vessel Code, Section II, Part D.

It is apparent from Table 2 that stainless steel and aluminum offer excellent performance in low temperature freezer applications compared to galvanized steel.

©2016 Colmac Coil Manufacturing, Inc.

Comparison: Working Pressure

Maximum Allowable Working Pressure (MAWP) is an important design parameter which must be calculated by the designer (or manufacturer) to insure the pressure bearing parts of the refrigeration system will not fail when exposed to the maximum anticipated operating pressures. Standard ANSI/IIAR 2-2008 (IIAR 2008) states that, for forced air evaporator coils: "Minimum design pressure shall be 150 psig [1030 kPa gage] or in the case where hot gas defrost is utilized, minimum design pressure shall be 250 psig [1720 kPa gage] or the design pressure of the high side source of hot gas, whichever is greater" (Section 8.1.1.1). The standard also states that, for air-cooled ammonia condensers: "Minimum design pressure shall be 300 psig [2070 kPa gage]" (Section 7.1.1.1).

The MAWP for a pressure vessel (i.e. evaporator pipe or tube) can be easily calculated from the ASME Pressure Vessel Code Section VIII when the following parameters are known: diameter, wall thickness, corrosion allowance, maximum allowable stress, and joint efficiency. Table 3 below shows calculated MAWP for 7/8" (22 mm) diameter tubes of various metals and commonly used wall thicknesses.

TABLE 3

MAX. ALLOWABLE WORKING PRESSURE FOR SHELLS UNDER INTERNAL PRESSURE

(CALCULATIONS BASED ON ASME SECTION VIII, 2002 ADDENDA, UG-27)

Pipe/Tube Dia., (in)	Pipe/Tube Wall, (in)	Pipe/Tube Matl	Corrosion Allowance, (in)	Max. allowable Working Press, bar (P)	Max. allowable Working Press, psig (P)	Max. allowable Stress Value (PSI) (S)
7/8	0.028	304L SST	0.002	51	738.2	14200
7/8	0.049	SA-179 CS	0.002	88	1284.7	13400
7/8	0.065	3003 Alum	0.002	31	443.7	3400

As shown in the table, the calculated MAWP for all of the metals being compared easily exceed the 300 psig mentioned above from ANSI/IIAR-2.

Comparison: Cost and Weight

The relative cost (and resulting price) and weight of an evaporator are obviously important considerations when selecting the appropriate type of evaporator construction for a given project. On a per pound basis, carbon steel is lower in cost than both stainless steel and aluminum. This cost differential is offset for aluminum, however, by the metal's low density. Since stainless steel has such a high tensile strength (see Table 1), the wall thickness of the stainless steel tubing can be safely reduced, which reduces the tubing cost per foot accordingly. The expensive process of hot dip galvanizing is not required for stainless tube/aluminum fin construction, which further offsets the higher cost per pound of these metals compared to carbon steel.

In order to make an accurate comparison of the three types of construction (Stl/Zn, SST/Al, and Al/Al) a calculation of relative weight and cost (using current material costs) was made for a typical ammonia evaporator coil block having the following characteristics:

- 7/8" (22 mm) diameter tubes
- 45" FH x 162"FL (1143mm FH x 4115mm FL) – 8 Rows – 4 FPI
- Approximate cooling capacity = 15 TR (53 kW)

Cost:

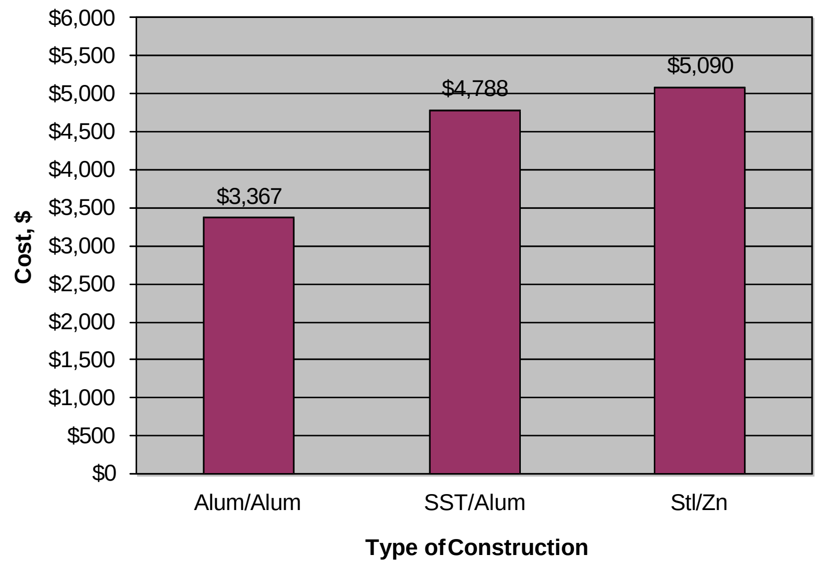
Figure 1 shows the cost comparison for the three types of construction. As mentioned above, the low density of aluminum combined with its relatively low cost per pound makes Al/Al construction the lowest cost type of construction.

©2016 Colmac Coil Manufacturing, Inc.

Generally speaking the following conclusions can be made:

1. Stl/Zn construction is most expensive,
2. SST/Al construction costs slightly less than Stl/Zn,
3. Al/Al construction offers lowest cost
   - 25 to 30% lower cost coil block compared to Stl/Zn,
   - 12 to 15% lower cost air cooler compared to Stl/Zn.

FIGURE 1
Ammonia Evaporator Cost Comparison
7/8 45"x162"-8R-4F Coil Block



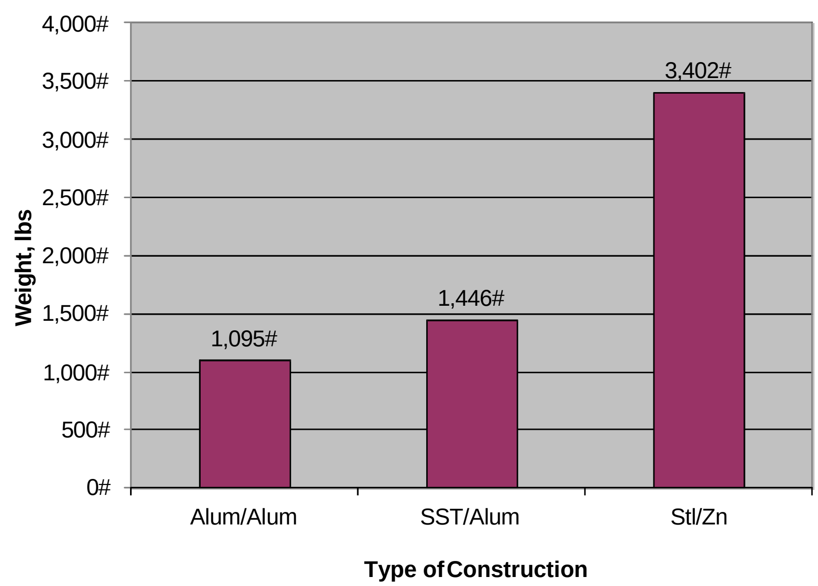
Weight:

The very low density of aluminum makes it an ideal metal to use for heat exchanger fins when weight is a concern. Table 1 shows densities for carbon steel, zinc, and aluminum. The densities of steel and zinc (galvanized steel) are approximately 3 times greater than aluminum. In a refrigeration evaporator, the fins represent approximately ½ the total weight of the coil block. Most of the remaining weight of the coil block is contributed by the tubes and headers.

Tensile and yield strength of the tubing and header metal will affect the wall thickness required for a given working pressure. The higher the tensile strength, the thinner the allowable wall thickness and the lighter the weight of the tubing. From Table 1 it is apparent that tubing made of stainless steel will have a thinner wall thickness and lighter weight when compared to carbon steel tubing for a given calculated working pressure and burst pressure.

Using appropriately selected stainless steel tubing with aluminum fins produces a coil block that is significantly lighter in weight than the same size galvanized steel coil block. A coil block made with both aluminum tubes and fins is even lighter in weight. Figure 2 shows the calculated weights for the three types of construction.

FIGURE 2
Ammonia Evaporator Weight Comparison
7/8 45"x162"-8R-4F Coil Block

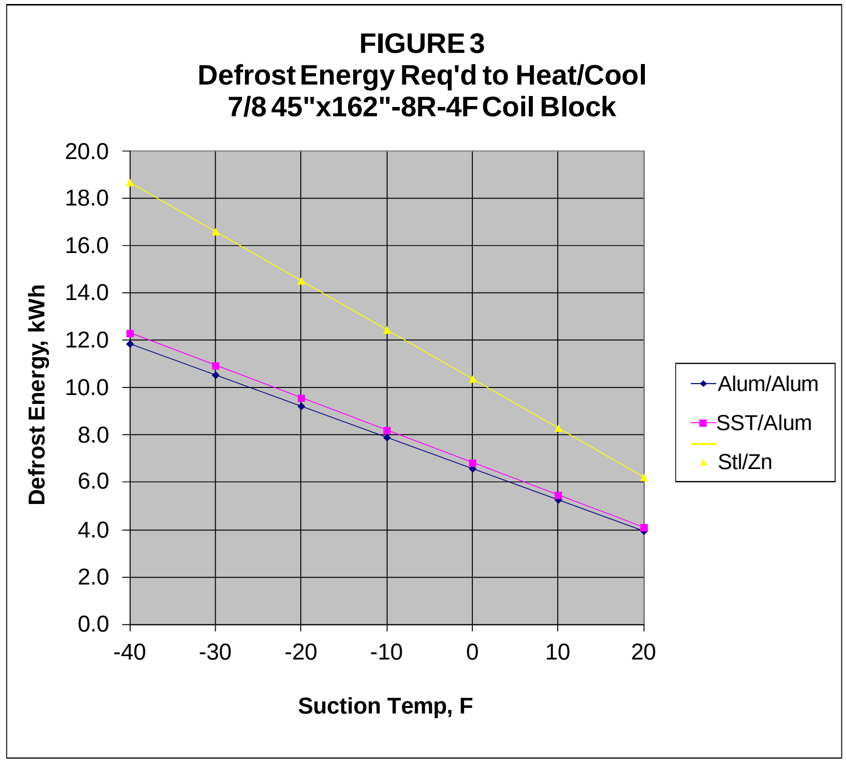


As can be seen in Figure 2, the calculated weight of the galvanized steel (Stl/Zn) coil block (3,402 lbs) is 2.4 times greater than a stainless tube/aluminum fin (SST/Alum) coil block (1,446 lbs), and 3.1 times greater than an aluminum tube and fin (Al/Al) coil block of the same size.

Air coolers are often mounted on the ceiling or roof of the refrigerated building. The weight of the air coolers has a significant impact on the structural design of the building and is of particular importance in high seismic areas. SST/Al and particularly Al/Al air coolers from Colmac offer architects and engineers a new replacement technology to traditional heavy galvanized air coolers. This weight advantage

©2016 Colmac Coil Manufacturing, Inc.

can be used to significantly reduce the cost of building structural members.
The lighter weight of SST/Al and Al/Al air coolers from Colmac also offer installers improved safety for workers when rigging and handling. It is easy to visualize the safety advantages of mounting a cooler weighing only 2,000 lbs in a building with a 25 foot ceiling compared with a heavy galvanized steel cooler of the same capacity weighing 5,000 lbs or more!



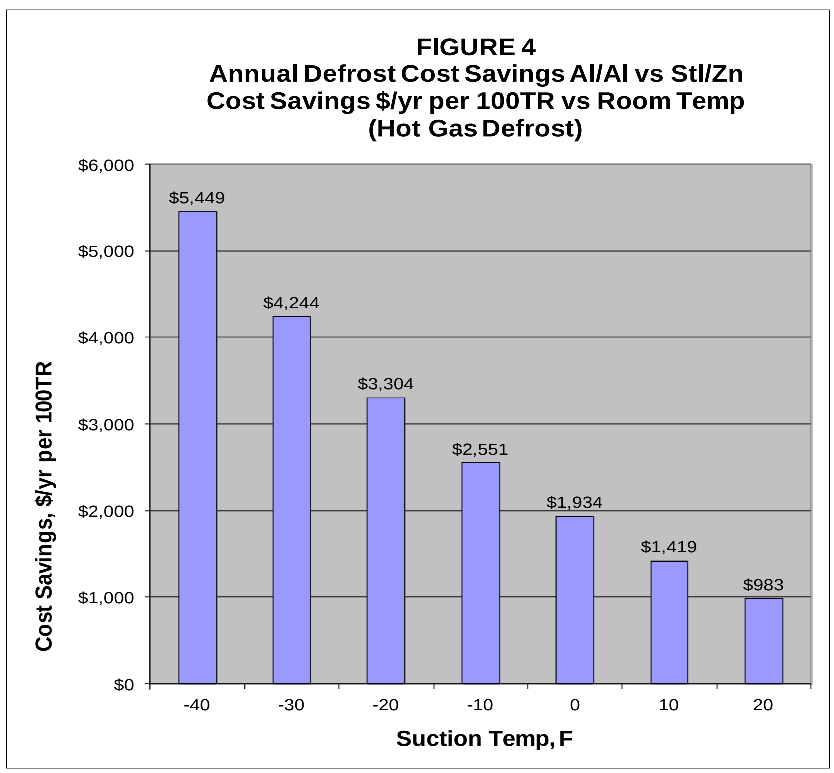
Comparison: Performance

The thermal conductivity of aluminum is 4 ½ times higher than steel, and 2 times higher than zinc. Thermal conductivity of the fin material has a direct effect on heat transfer efficiency, the higher the better. Aluminum is superior to galvanized steel for efficient heat transfer. The measured performance of an Al/Al ammonia evaporator will be approximately 12 to 14% higher than a Stl/Zn evaporator having the same dimensions (Stencel 1992). A SST/Al ammonia evaporator will have slightly lower performance than the Al/Al due to the poor conductivity of the stainless steel tubing, but will still outperform a Stl/Zn evaporator of the same dimensions by 10 to 12%.

The superior cooling capacity of Al/Al and SST/Al construction compared to Stl/Zn allows the designer the choice between (a) selecting an evaporator having fewer rows and/or wider fin spacing for lower first cost, or (b) using the same size unit (same rows and fin spacing) and operating at higher suction pressures with resulting reduced operating costs.

Comparison: Defrost Energy

The high thermal conductivity of aluminum fins also produces faster, more effective defrosts compared to galvanized steel. SST/Al and Al/Al evaporators simply defrost faster and better than Stl/Zn steel coils.



SST/Al and Al/Al evaporators also perform better than Stl/Zn during defrost on an energy basis. A substantial amount of energy is expended during defrost to heat the mass of metal in a refrigeration evaporator up to the defrost temperature, then to cool the metal back down to operating temperature after defrost. When the density of the metal is multiplied by the thermal conductivity the product indicates the amount of energy required to heat (or cool) a heat exchanger of a given volume by one degree.
Based on this analysis, a comparison was made for our example evaporators. Figure 3 shows the total amount of energy required to heat the coil block from suction temperature to 50F and then cool it back to down again. This energy is expended every defrost cycle.

©2016 Colmac Coil Manufacturing, Inc.

As shown in Figure 3, the Al/Al and SST/Al coil blocks consume significantly less energy to heat up and cool down during defrost (30 to 35% less) than the Stl/Zn coil block. This reduced amount of energy required for heating and cooling metal results in significant ongoing savings in operating costs compared with traditional energy consuming Stl/Zn evaporators.

Defrost Energy Savings

This difference in energy consumption can be converted to cost savings by making assumptions for number of defrosts per day, days of operation per year, and the electric utility rate. A cost calculation was made for 100TR (350 kW) of evaporator capacity, assuming 6 defrosts per day for 365 days/year, a utility rate of $0.10/kWh, typical screw compressor system COPs (assumed defrost is with hot gas), and a hot defrost pressure regulator setting of 74.3 psig (50F). Calculated cost savings for hot gas defrost are shown in Figure 4.

Comparison: Corrosion Resistance

Corrosion of heat exchangers by contact with, or proximity to foodstuffs is a concern in food processing facilities (Nelson 2007). All foodstuffs are mildly acidic. Aluminum and stainless steel are both more corrosion resistant than galvanized steel when exposed to:

- Acetic and citric acids (dairy products, citrus products)
- Fatty acids (anti-caking agents, lubricants)
- Lactic acids (bread, confections, beverages, fermentation, blood)

Aluminum is also more corrosion resistant than galvanized steel in the presence of:

- Sodium chloride (preservation of meats and vegetables)
- Sulfur dioxide (grape storage)

Neither galvanized steel nor aluminum is recommended for exposure to nitrites (cured and smoked meats). Stainless steel is the suggested material to use in the presence of nitrites.

Generally speaking, aluminum and stainless steel are better metals to use than galvanized steel where there is concern about corrosion due to contact with most foodstuffs.

Cleaning Chemicals

In order to control contamination of food in processing facilities, various chemical compounds are used for cleaning and sanitizing. Cleaning is defined as the removal of organic soils (fats and oils) and/or inorganic soil (mineral scale or stains). Sanitizing is defined as the process of treating cleaned surfaces to effectively kill or remove pathogens.

The USDA requires that these two processes, cleaning and sanitizing, be done separately. Cleaning and sanitizing chemicals used in the food processing industry fall into four categories:

1. Acidic
2. Strongly Alkaline
3. Mildly Alkaline
4. Chlorine Based

Zinc, Aluminum, and Stainless Steel (304L, 316L) react differently to these cleaning chemicals (NACE 1985). In some cases severe corrosion and metal loss can occur. Generally speaking, corrosion and rate of metal loss increases with:

- Increasing temperature
- Increasing concentration
- Longer duration of exposure
- Increased aeration of the solution

Following is a summary of how each of these metals reacts to various environments and recommendations regarding cleaning and sanitizing chemicals appropriate for each.

©2016 Colmac Coil Manufacturing, Inc.

Aluminum

General

- The protective oxide layer forms very quickly when the metal is exposed to air and is very stable in the pH range of 4 to 9 (Davis 1999).
- Aluminum corrodes very quickly when exposed to strong alkaline cleaners such as caustic soda (sodium hydroxide) (Alum Assoc 1994) .
- Aluminum is also attacked by strong acids as well as chlorine based cleaners (concentrated sodium hypochlorite).

Cleaning

- Foaming mildly alkaline cleaners are recommended for the removal of animal fats (organic soil). Example: ZEP FS Strike Three, ZEP FS Foamate

- Foaming mildly acidic cleaners (phosphoric acid based with pH >4) are recommended for removal of stains and scale (inorganic soil). Example: ZEP Formula 7961

Sanitizing

- Spray-on quaternary ammonium type sanitizers are recommended. Example: ZEP FS Amine Z, ZEP Amine A
- The use of sodium hypochlorite in high concentrations can cause pitting of aluminum and is NOT recommended for sanitizing.

Stainless Steel (304L, 316L)

General

- The chromium in stainless steel forms a very dense passive film layer which is generally very stable over a wide pH range (Carpenter 1987).
- These alloys are resistant to strong alkaline cleaners such as caustic soda (sodium hydroxide).
- Halogen salts (primarily chlorides) penetrate the passive layer and can result in pitting and/or stress corrosion cracking.
- Exposure to sodium hypochlorite, or hydrochloric acid solutions, in high concentrations will result in pitting and/or stress corrosion cracking.

Cleaning

- Foaming mildly alkaline cleaners are recommended for the removal of animal fats (organic soil). Example: ZEP FS Strike Three, ZEP FS Foamate
- Foaming mildly acidic cleaners (phosphoric acid based with pH >4) are recommended for removal of stains and scale (inorganic soil). Example: ZEP Formula 7961

Sanitizing

- Spray-on quaternary ammonium type sanitizers are recommended. Example: ZEP FS Amine Z, ZEP Amine A
- The use of sodium hypochlorite in high concentrations will cause pitting and/or stress corrosion cracking and is NOT recommended.

Zinc (galvanized steel)

General

- The oxide layer forms quickly in the presence of air and is stable in the pH range of 7 to 12 (Stencel 1993).
- Zinc corrodes very quickly when exposed to acidic solutions, even mildly acidic.
- The metal is resistant to corrosion by alkaline cleaners such as caustic soda (sodium hydroxide).

Cleaning

- Foaming mildly alkaline cleaners are recommended for the removal of animal fats (organic soil). Example: ZEP FS Strike Three, ZEP FS Foamate
- Acidic cleaners of all types (pH <7) will result in rapid metal loss and are to be avoided. This makes removal of stains and scale (inorganic soil) very difficult and problematic.

Sanitizing

- Spray-on quaternary ammonium type sanitizers are recommended. Example: ZEP FS Amine Z, ZEP Amine A
- The use of sodium hypochlorite is NOT recommended.

©2016 Colmac Coil Manufacturing, Inc.

Figure 5
Old Flange Union vs New Colmac BiM Technology

Figure 6
Al/Al Evaporator with Colmac BiM Connections

Comparison: Reliability

In a recent survey of ammonia refrigeration end users, it was found that 95% of all incidental ammonia leaks occur at flange union pipe connections, including coil connections. With Stl/Zn and SST/Al construction the coil connections are typically welded and so the potential for ammonia leaks greatly reduced. Al/Al coil connections traditionally used dielectric type flange unions which are prone to leaks over time. A new technology is now available from Colmac which eliminates the need for flange union coil connections on Al/Al construction. Colmac BiM couplers make the transition from the aluminum coil liquid and suction connections to the system steel (or stainless steel) piping via a proprietary metallurgical bonding process, eliminating the need for bolts, gaskets, and flanges. This new technology is shown below in Figures 5 and 6.

Conclusions:

Three types of ammonia evaporator construction (Al/Al, SST/Al, and Stl/Zn) have been analyzed and compared.

1. Al/Al construction was found to have:
    a. Lowest first cost
    b. Lightest weight
    c. Best performance
    d. Lowest operating cost
2. Unlike Stl/Zn which becomes brittle and requires special design considerations, both SST/Al and Al/Al construction retain full strength and do not become brittle, even at very low temperatures.
3. When Al/Al ammonia evaporators are installed in food processing plants and exposed to cleaning and sanitizing chemicals:
    a. Highly alkaline (pH >10) cleaners should be avoided. Foaming mildly alkaline cleaners are recommended.
    b. Sodium hypochlorite based sanitizers should be avoided. Quaternary ammonium sanitizers are recommended.

©2016 Colmac Coil Manufacturing, Inc.

Bibliography

Alum Assoc 1994. “Guidelines for the use of Aluminum with Food and Chemicals”. Sixth Edition. *The Aluminum Association,* WA DC.

Carpenter 1987. “Selecting Carpenter Stainless Steels”. *Carpenter Technology Corporation*, Reading, PA. pp 211.

Davis J.S. 1999. “Corrosion of Aluminum and Aluminum Alloys”, *ASM International*, Materials Park, OH

IIAR 2008. Standard ANSI/IIAR 2-2008 “Equipment, Design, and Installation of Closed-Circuit Ammonia Mechanical Refrigerating Systems. *International Institute of Ammonia Refrigeration*. Alexandria, VA

NACE 1985. “Corrosion Data Survey”. *National Association of Corrosion Engineers*, Houston, TX.

Nelson, B. 2003. “Made for Ammonia”. *BNP Media*, Troy, MI. Process Cooling & Equipment, July-August 2003.

Nelson, B. 2007. “Five Advantages of Aluminum Evaporators”. *BNP Media*, Troy, MI. Process Cooling & Equipment, January-February 2007, pp 25.

Stencel, M. 1992. “Relative Performance of Aluminum and Galvanized Steel Evaporators”. *International Institute of Ammonia Refrigeration*. Alexandria, VA. IIAR 14th Annual Meeting Proceedings, pp 197.

Stencel, M. 1993. “Aluminum and Galvanized Steel Evaporators: Effects of the Operating Environment”. *International Institute of Ammonia Refrigeration*. Alexandria, VA. IIAR 15th Annual Meeting Proceedings, pp 264.

For more information, please contact Colmac Coil Manufacturing, Inc.
mail@colmaccoil.com | (800) 845-6778 | (509) 684-2595
P.O. Box 571, Colville, WA. 99114-0571 | www.colmaccoil.com
© 2016 Colmac Coil Manufacturing, Inc.

©2016 Colmac Coil Manufacturing, Inc.