Innovations for the manufacture of industrial heat exchangers

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Introduction

A heat exchanger is a device that transfers heat from a hot to a cold fluid or gas. The process can be as simple as an air conditioner or as complicated as the reclamation of heat energy from the exhaust of a gas turbine engine. But no matter how simple or complicated the process, the basis is the same, the transfer of heat from one substance to another.

Heat exchangers are not new but have been around for a very long time and actually occur naturally in nature. Many animals use naturally occurring heat exchangers to regulate body temperature. For example, capillaries near the skin help heat or cool the body or specific body parts. Warm blood in the arteries gives up some of its heat to the veins, which run in a countercurrent direction. Mammals, with their ability to perspire, employ a sophisticated cooling technique of evaporation to cool the body. Leafy plants use transpiration by pulling cool water from their roots to their leaves where the water evaporates and cools the plant. Man has “industrialized” these systems to create devices that simulate what nature already proved works very well.

Classifications

Heat exchangers are used extensively in fossil-fuel and nuclear power plants, gas turbines, heating and air conditioning systmes, refrigeration and chemical plants. Depending on the special purpose of the heat exchanger device, it can be classified as a boiler, an evaporator, a condenser, a cooler, or a superheater. Fundamentally, they are much the same, exchanging cool and warm substances. The two best known types of heat exchangers are shell and tube, and plate.

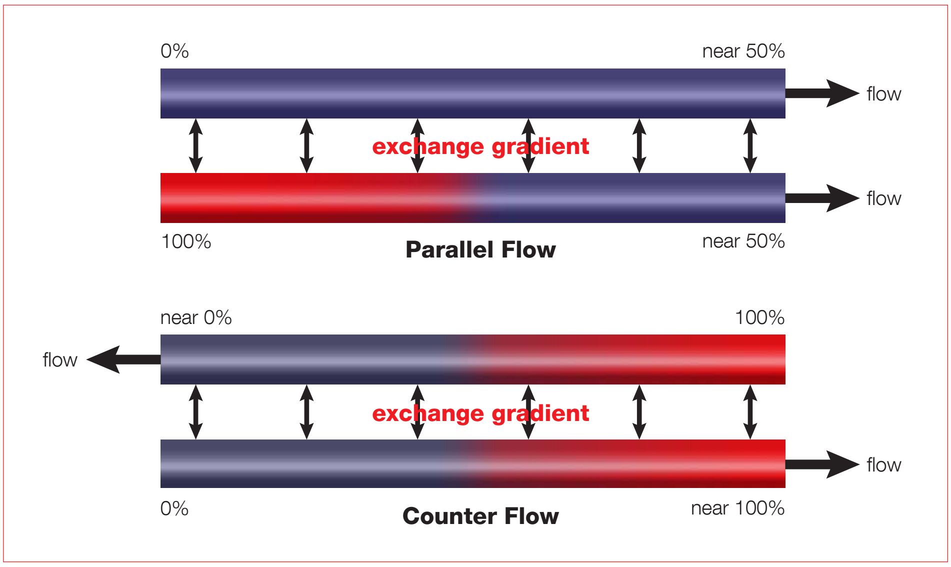

Figure 1. Comparison of parallel flow (top) and counter flow (bottom) heat transfer. Counter flow is much more efficient

The shell and tube types are typically used for higher pressure applications because of their design. They consist of tube bundles through which either the fluid to be heated or the fluid to be cooled runs. The second liquid or gas then runs over these tubes to complete the temperature exchange.

The second type heat exchanger, that of the plate variety, is comprised of many thermally conductive thin plates stacked so there are gaps that allow the flow of liquid or gas between the plates over the large surface area. In a given space, the plate type heat exchanger is more effective than the shell & tube heat exchanger because of the larger surface area for exchange.

Heat exchangers are classified by the flow pattern used to exchange hot and cold. When two fluids flow in the same direction, it is referred to as a “parallel flow” type. A more efficient design is the “counter-flow” heat exchanger where the fluids flow through the heat exchanger in opposite directions. (Figure 1). The counter flow system that has enough length and a low flow rate can result in the best transfer of heat into or out of the process. The best that the parallel-flow type heat exchanger can achieve in heat transfer is 50% and even this rate deteriorates over time. Design of the flow patterns, use of fins and grooves increase the surface area and turbulation of the gasses or liquids allowing for better heating and cooling transfer. (Figure 2).

Fabrication and joining

Historically heat exchangers were joined / assembled by welding. This process was readily available and provided strength to the assembly. Today, there are still many types that are welded because of their mass or service conditions, but much of the joining has moved to brazing. The design (hundreds of extremely thin 0.127 mm [0.005 inch] sheets) and base metals of the more complex assemblies have pushed manufacturers to different types of joining. These newer types of heat exchangers have benefited from advances in furnaces, atmospheres and filler metals making brazing the method used to meet the challenging service conditions and applications.

Heat exchangers today are manufactured with steel, stainless steels, copper, nickel-based and aluminum-based metals. The brazing filler metals fall into the same metal categories: copper, copper alloys, aluminum alloys and nickel filler metals (Table 1). Atmospheres appropriate to the base metal / filler metal combinations are used to braze the various types of heat exchangers (Table 2). In the last decade, more emphasis has been placed on stainless steel heat exchangers brazed with nickel-based filler metals. Heat exchangers manufactured with these high temperature braze alloys are able to meet the current stringent emission regulations and can be run at higher service temperatures for new applications.

The nickel filler metals show a high resistance to oxidizing and corrosive atmospheres that are common in automotive and aerospace applications. So, many of the manufacturers have families of heat exchangers brazed with nickel filler metals. While there are many types of nickel filler metals, three have become the most commonly used. They are commercially known as BNi-2, BNi-5, and NiCrSiP. There are some technical limits with the traditional nickel-based filler metals as described in Table 3. Boron diffusion can reduce the strength of the thin sheet metal used in plate heat exchangers. For this reason,

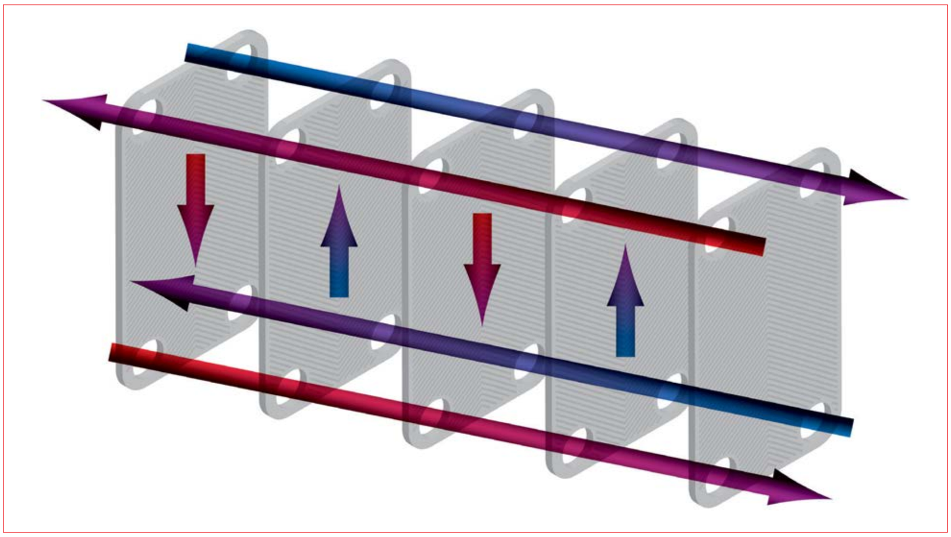

Figure 2. Schematic of a counter flow, plate heat exchanger

Base Metals	Filler Metals				
	Copper	Copper Alloys	Aluminum Alloys	Nickel Alloys	Iron Alloys
Steels	●	●		●	●
Stainless Steels	●	●		●	●
Copper	●	●			
Copper Alloys	●	●			
Aluminum			●		
Aluminum Alloys			●		
Nickel Alloys				●	●

Table 1. Braze Filler Metals / Base Metal Combinations

Atmospheres	Base Metal / Filler Metal				
	Steel	Copper	Copper Alloys	Nickel Alloys	Iron Filler Metals
Gas [Endo / Exo]	●	●	●		
Inert Gas (N_2, Ar)	●		●	●	●
Hydrogen	●		●	●	●
Vacuum	●		●	●	●

Table 2. Metal / Atmosphere Combinations

Filler Metal	Advantages	Disadvantages
BNi-2	■ Low braze temperature ■ Many suppliers / stocked product	■ Boron diffusion into base metal ■ Limited corrosion resistance ■ Cost (83% nickel)
BNI-5	■ Boron free ■ High corrosion resistance	■ High braze temperature ■ Limited burst strength ■ Cost (70% nickel)
NiCrSiP	■ Low braze temperature ■ Boron free ■ High corrosion resistance ■ High strength	■ Fewer suppliers ■ Cost (65% nickel)

Table 3. Advantages and disadvantages of traditional braze filler metals used for heat exchangers

boron-free filler metals are desirable for heat exchangers constructed from stainless steel. Some of the boron-free alloys have higher melting points, which must be brazed in high-temperature braze cycles. Brazing stainless steels at high temperatures for long periods can cause grain growth and may degrade the strength of the sheet metal, reducing the overall strength or life expectancy of the heat exchanger.

New filler metals for heat exchangers

In support of the evolving heat exchanger industry, three new braze filler metal compositions have been developed (Table 4).

a) Nichrome-based Amdry™ 105
c) High-chrome, stainless-based Amdry 805.

All of the compositions contain high amounts of chrome (at least 23%) and employ controlled amounts of silicon and phosphorus as alloying elements to depress the melting point.

It should be noted that all Amdry 105 and Amdry 805 filler metals are boron free. Carefully controlled amounts of silicon and phosphorus have been utilized as melt depressants. While Amdry 105, a nickel-based braze alloy, contains no iron in its composition, Amdry 805 is a stainless steel-based alloy with a small amount of nickel (15 weight percent) contained in it. This addition of nickel in Amdry 805 was made to optimize the melting point as well as to retain the austenitic phase structure in the alloy.

Braze performance

The following tests were conducted to evaluate the suitability of these filler metals for brazing applications:

1. Measurement of solidus and liquidus temperatures by DTA (Differential Thermal Analysis).

2. Vacuum furnace brazing of a T-joint and metallography of the joints

3. Corrosion tests in several aqueous solutions

4. High temperature oxidation tests at 815 °C (1500 °F)

Measurement of solidus and liquidus temperatures: These were done in commercial test labs that perform these measurements routinely. A forward heating cycle and a cooling cycle were used. The

	Ni	Cr	Fe	Si	P
Amdry 105	Balance	23	0	6.5	4.5
Amdry 805	15	29	Balance	6.5	6.5

Table 4. Nominal Chemical Composition (wt %)

measured solidus and liquidus temperatures are shown in Table 5, below.

Filler Metal	Solidus (°C)	Liquidus (°C)
BNi-2	970	1000
Amdry 105	990	1010
Amdry 805	1075	1105
BNi-5	1080	1135

Table 5. Measured solidus and liquidus temperatures

It should be noted that BNi-2 and BNi-5 alloys are used for comparison purposes. The three new Amdry braze filler metals have melting points that are in the intermediate range between the melting points of BNi-2 and BNi-5. Amdry 105, which does not contain any iron, has the lowest melting point (comparable to BNi-2). As the iron content increases, the melting points also increase. Amdry 805 has the highest melting point; however, this is still lower than the melting point of BNi-5. It should also be noted that the temperature differential between the solidus and liquidus in these alloys is on the order of 20 to 30 degrees Celsius as compared to 30 to 55 degrees Celsius in conventional alloys such as BNi-2 and BNi-5. Such a narrow gap is an indication of the ‘flowability’ of the alloy at brazing temperatures; thus enabling ‘tight’ joints with the highest strengths.

Vacuum furnace brazed joints

The new filler metals were applied to a stainless steel T-joint with a 0.05 to 0.15 mm (0.002 to 0.006 inch) gap and vacuum furnace brazed. The joints showed that all the alloys had excellent flow and filled the gaps with clean fillets. A typical microstructure of these braze joints is shown in Figure 3.

Similar microstructures were obtained for all the new filler metals. It may be noted that the vacuum brazing atmosphere must be carefully controlled for these alloys. Specifically, these alloys contain high amounts of oxygen-sensitive elements such as chromium and silicon. Also, they do not contain fluxing elements, such as boron, that would inherently tolerate some oxygen partial pressures in the vacuum furnace. For these reasons, we have observed that leak up rates of less than 30 microns per hour and vacuum levels of 1×10^{-4} Torr work best. The furnace cycles may include a soak at approximately 400 °C (760 °F) for about 30 minutes, another soak at 960 °C (1760 °F) for 30 minutes and brazing at recommended temperatures for 15 to 30 minutes. Recommended brazing temperatures are typically 50 °C (90 °F) above the liquidus. This will ensure excellent melting and flow of the filler metal into the joint gaps.

Similar experiments have demonstrated that the above filler metals braze well on several ferrous base metals, nickel alloy base metals and, in some cases, even copper base metals.

Corrosion resistance tests

The resistance of these new alloys to several types of corrosive media was studied. Separate brazed coupons were immersed in a ten percent solution of sulfuric acid, a ten percent solution of hydrochloric acid and a saturated salt solution. The coupons were immersed at room temperature for 150 hours and examined under the microscope for pitting, etching or other possible corrosive damage. They were also examined for stability and strength before and after the immersion test.

High temperature oxidation resistance was measured by exposing melt buttons to a temperature of 815 °C (1500 °F) for 24 hours and measuring for weight gain.

In all cases, the brazed samples of Amdry 105 and Amdry 805 exhibited excellent stability and minimal degradation.

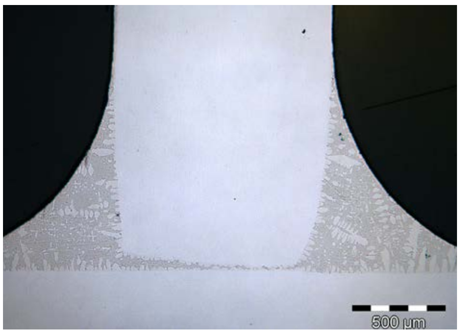

Figure 3. Brazed joint on a T-speciman (Amdry 105)

It is believed that the presence of at least 23 percent chromium and 6 percent silicon in these alloys enhances their oxidation and corrosion resistance.

Benefits

There are four key areas in which the new Amdry braze filler metals will benefit the manufacture of heat exchangers.

Effective: The Amdry 105 produces high quality braze joints that have excellent corrosion resistance and strong joints when used on steels, stainless steels and superalloy substrates. They are boron free reducing the possibility of erosion on thin sheets or tubes in the heat exchanger. The alloys flow well into long narrow gaps making them a good selection for tube & shell heat exchangers where the tubes are brazed into headers.

Efficient: The clean and dry gas atomized powders have a precise chemistry and particle size that insure reproducibility of the brazing process. The powders are designed for vacuum brazing, but can also be used in gas atmospheres such as hydrogen, nitrogen, or argon. The temperature range for brazing these new alloys is the same as the alloys currently used to braze the heat exchangers, coolers, and boilers, so little or no change is necessary to the production process in order to use these new alloys.

Economical: Amdry 805, which is iron-based is a money saver in the brazing process. The unique chemistry of Amdry 805 can be 30% less than the nickel-based filler metals. It is not sensitive to the fluctuating metal prices for nickel that will help when long-range programs require stable costs.

Environmentally friendly: The ability to use these alloys in vacuum furnace brazing eliminates the risk of any environmental hazard. Furthermore, besides their availability as dry, gas atomized powders, they are also available in pre-mixed paste, tape and customized preforms, allowing application with little or no waste.

Conclusion

The new alloys — Amdry 105 and Amdry 805 — belong to a new family of boron-free, high-chromium–containing filler metals that utilize relatively small amounts of silicon and phosphorus as melt depressants. Braze tests show that these alloys have melting points within the range of conventional nickel braze filler metals and are capable of producing excellent braze joints that can withstand the corrosive and oxidation conditions expected in modern high temperature applications like heat exchangers and catalytic converters. Amdry 105, a nickel-based filler metal, was developed as a benchmark brazing alloy. Subsequently, Amdry 805 was developed to maintain the high performance of Amdry 105, but with a reduced cost of the filler metal. This was accomplished by replacing a portion of nickel with iron. Based on the significantly lower cost of iron compared to nickel, it is estimated that raw material costs for Amdry 805 would be approximately 30 percent less when compared to conventional BNi-2 and BNi-5 alloys. Based on the technical performance and cost advantages, it is believed that these new alloys are worthy candidates for brazing heat exchangers and catalytic converters in order to meet the new application requirements in the marketplace today.

Acknowledgements
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Notes
- Amdry is a registered trade mark of Oerlikon Metco
- The composition of Amdry 805 is covered by a pending U.S. Patent Application by Oerlikon Metco

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Keywords
nickel braze filler metal, iron braze filler metal, heat exchangers, catalytic converters, corrosion resistance, joint strength

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