BAHX

Brazed Aluminum Heat Exchangers

CHART®

Cooler By Design®

Chart pioneered the fabrication of large brazed aluminum heat exchangers in the 1950s, and has continued to be the industry innovator ever since.

Chart Energy & Chemicals , a wholly owned subsidiary of Chart Industries, Inc. (NYSE:GTLS), is a specialist in the design and manufacture of **Brazed Aluminum Heat Exchangers** (BAHX), which are mission critical for a wide variety of cryogenic processing applications where reliability and thermal efficiency are paramount.

Chart's heritage begins with the adaptation of the product from the aerospace industry in the 1950s. The company incorporates the former Altec and Marston brands and claims a significant number of 'world firsts' and an unrivaled track record. Chart was the first manufacturer to introduce vacuum brazing, developed the Core-in-Kettle®, mercury tolerant construction and, more recently, announced Smart Layer®.

Chart BAHX can be supplied as single units, manifolded assemblies or integrated solutions comprising fully assembled cold boxes including separator drums, vessels, interconnecting pipe work, valves, instrumentation and flanged connections for easy installation.

Through Chart Lifecycle we provide the most comprehensive after-sales and preventative maintenance program, including a site team that can be deployed worldwide.

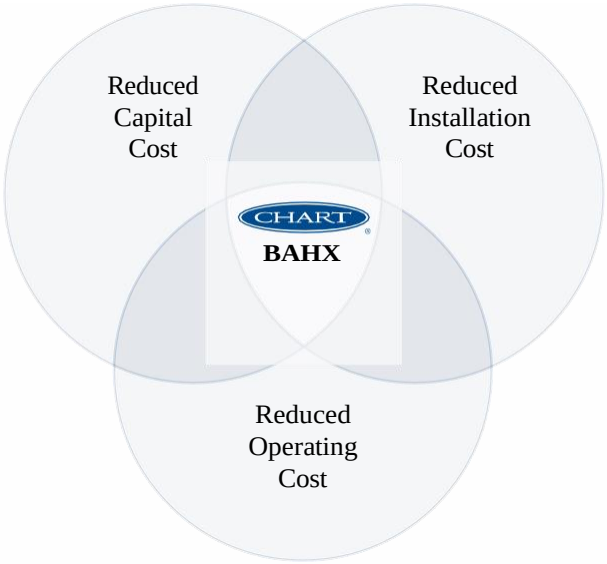
Contents

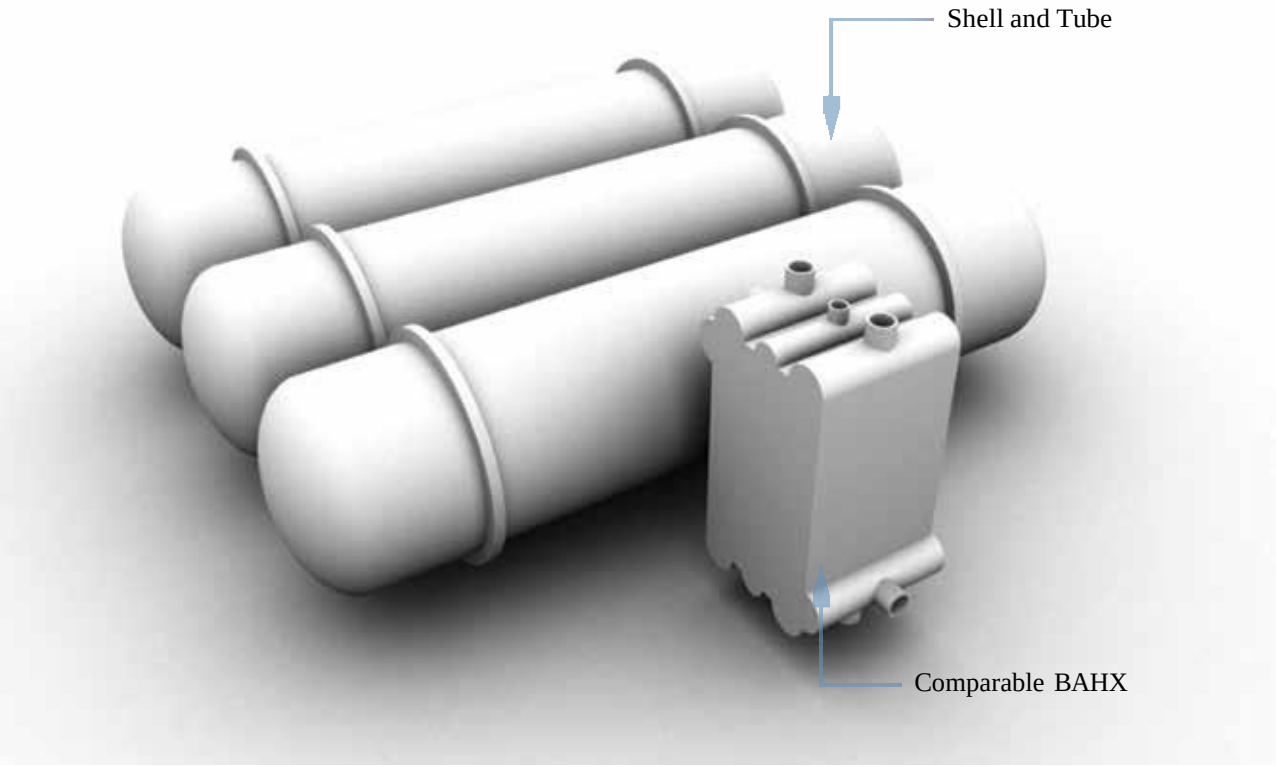
Superior Performance

A BAHX is typically 20% the size of a shell and tube exchanger of comparable performance. Furthermore, the alternating plate fin construction offers multiple stream capability and simplifies a series of shell and tube units to a single compact structure.

Chart BAHX = Reduced Capital, Installation and Operating Cost

- All aluminum construction for maximum heat transfer and thermal conductivity
- High performance heat transfer fins
- Custom design for optimized thermal and hydraulic performance
- 6 to 10x greater heat transfer surface area/volume
- 10 to 20x more UA/volume
- Multi-stream capability
- 25 to 50% lower initial cost
- Up to 95% less weight
- Less plant space required
- Reduced ancillary costs – installation, insulation, foundation, transportation
- Reduced temperature approaches, as low as 2°F (1°C), result in reduced compressor horsepower





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Applications

BAHX are at the heart of the cryogenic processes producing the industrial building blocks increasingly in demand throughout the world.

The industrial gas industry requires BAHX to produce the pure components of nitrogen, oxygen and rare gases in highly efficient cryogenic processes. BAHX are incorporated into hydrocarbon processing applications for the production of important basic products such as ethylene, propylene, hydrogen and natural gas, which all require cryogenic processing.

Worldwide demand for natural gas, driven by its economic and environmental benefits versus other fossil fuels, is predicted to increase for the foreseeable future. BAHX play a fundamental role in its purification and liquefaction and also enable the extraction of valuable by-products such as helium and natural gas liquids (NGL).

Industrial Gas Production
Air Separation
Nitrogen Liquefaction
Helium Liquefaction
Argon Recovery
Hydrogen Liquefaction
Carbon Capture

Natural Gas Processing
Nitrogen Rejection (NRU)
Helium Recovery
Natural Gas Liquids (NGL) Recovery
Ethane Recovery

Petrochemical Processing
Ethylene
Hydrogen Recovery (HYCO)
Propane Dehydrogenation (PDH)

Liquid Natural Gas (LNG)
Peak Shaving
Small & Mid-scale Liquefaction
Baseload
Floating LNG
Biogas Liquefaction

Baseload LNG liquefaction facility

Small-scale LNG liquefaction plant

Propane dehydrogenation unit

Nitrogen rejection unit

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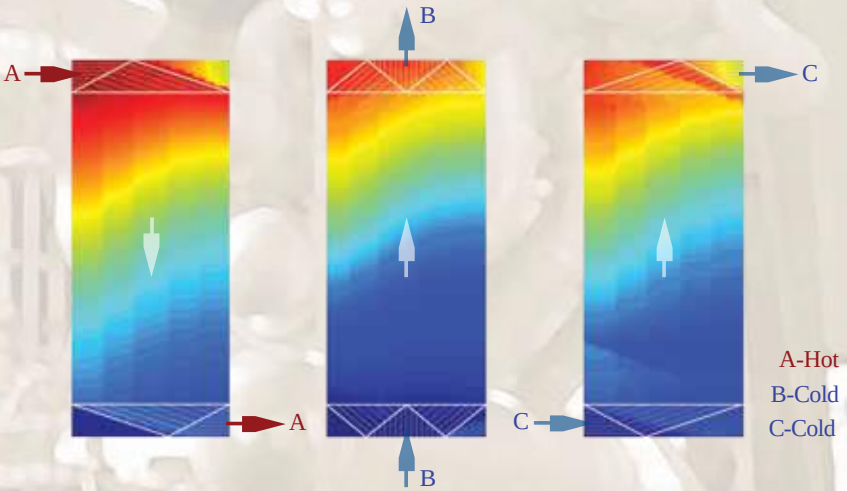
Custom Engineered

Chart BAHX are custom engineered to meet individual thermal and hydraulic performance requirements.

State-of-the-art software coupled with in-house engineering expertise and experience provide optimized design solutions incorporating all of the following:

- Achieve the required heat transfer performance for each process stream
- Work within the specified allowable pressure drops for each stream
- Incorporate multiple heat exchange duties into a single design
- Define the required number of process layers for each stream
- Produce the most efficient layer arrangement
- Specify component thicknesses according to mechanical strength requirements, operating conditions and the relevant design code
- Consideration of special customer requirements such as 2-phase distribution, thermosyphons, reflux condensing, transient operations
- Advanced transient thermal analysis capabilities to calculate the 3-dimensional internal fluid and metal heat exchanger temperatures. These analyses can be carried forward to predict potential fatigue damage and life expectancy of the equipment



As well as forming the basis of the comprehensive performance warranty, Chart design expertise adds another dimension to the customer's plant optimization by facilitating the evaluation of multiple cases and provides early equipment configurations and dimensional sketches for plant layouts.

Sophisticated 3D CAD modelling, FEA and dynamic thermal analysis software is employed by Chart.

Electronic data transfer completes the smooth and prompt interface between Chart equipment designs and the customer's plant layout.

Chart's proven software provides detailed information required to optimize designs and evaluate various operating conditions including transients.

Chart continues to develop its product and design capabilities through feedback and collaboration with various industry leaders and longtime, consistent users of BAHX.

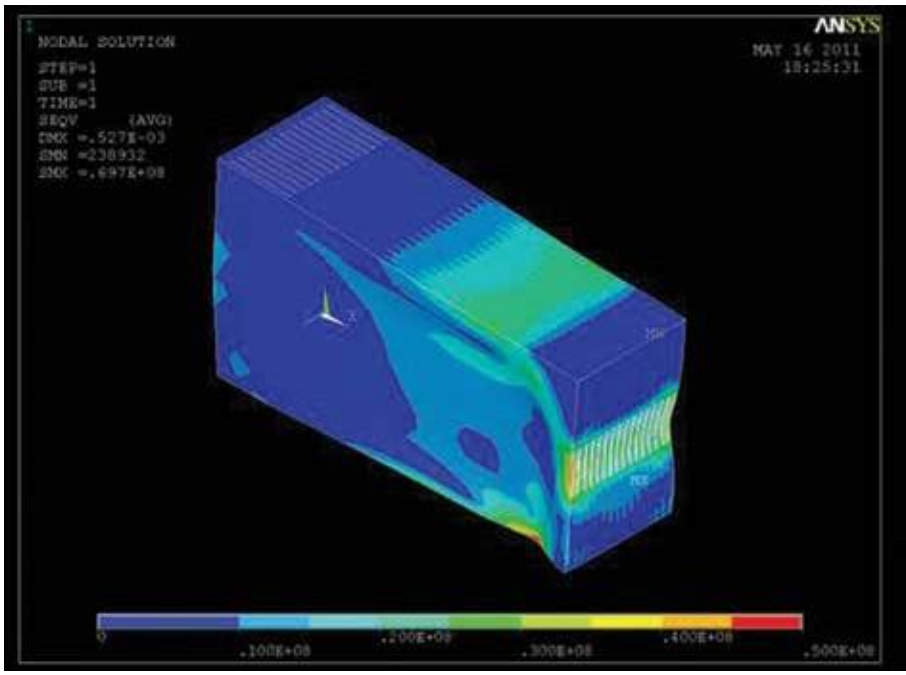
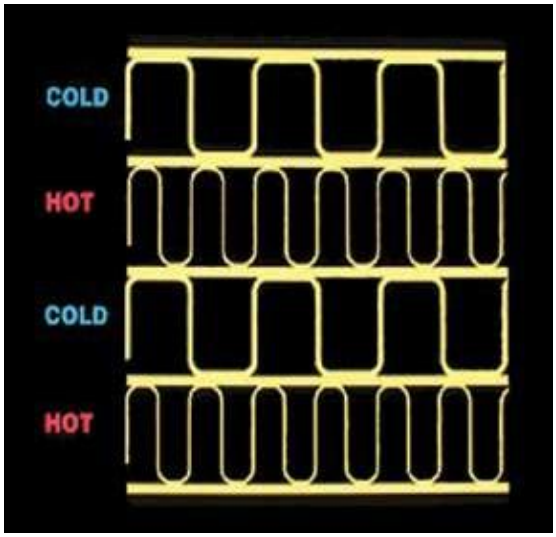


Chart helps customers understand the effects of severe operating conditions through detail stress analysis



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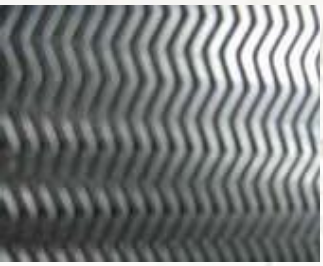


Maximum Heat Transfer Performance

Heat is transferred between layers across the parting sheets (primary heat transfer surface) while the fins provide an enhanced secondary heat transfer surface.

Chart has developed 4 primary fin types each offering different thermal and hydraulic performance characteristics.

For maximum design versatility the height and density of each fin type can be varied resulting in a multitude of performance characteristics.

Different fin types can be combined in a single stream. This approach is common when the heat transfer duty requires a phase change e.g., an incoming fluid is boiled and then superheated.

The hydraulic and thermal performance characteristics of all Chart fins is based on extensive laboratory testing and decades of successful field operation.

Construction

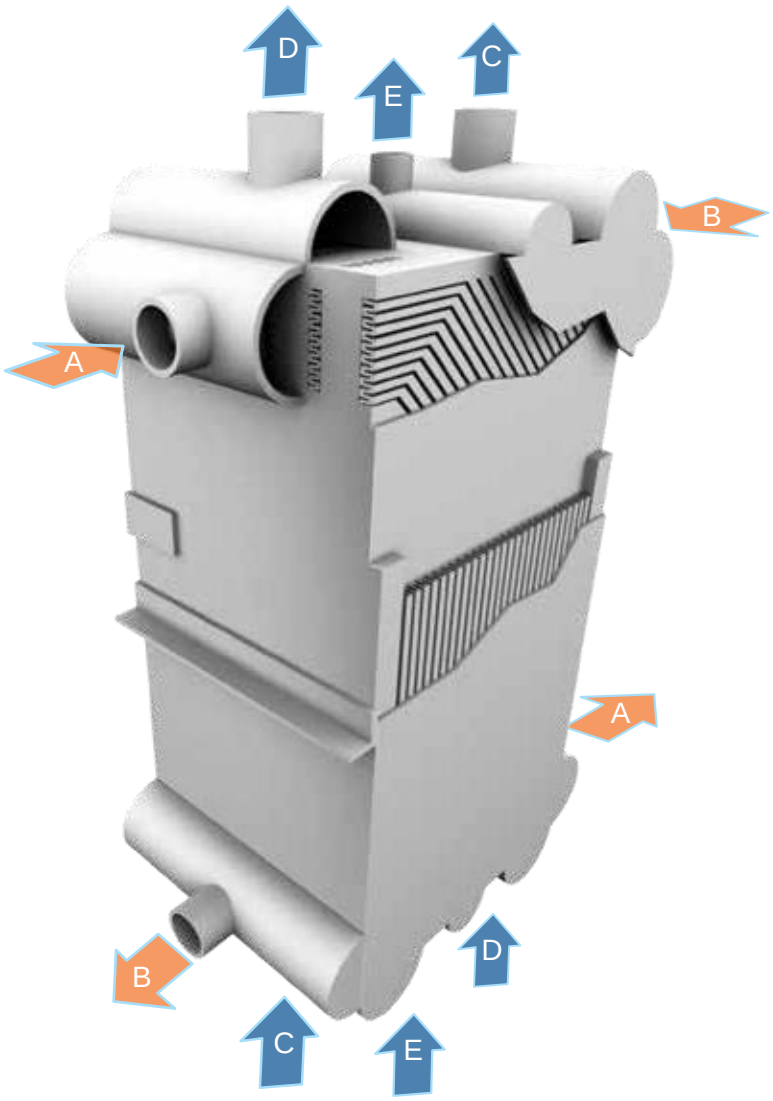
Chart BAHX owe their inherent versatility and high-characteristics to their aluminum plate-fin construction.

Each BAHX consists of alternating layers of corrugated fins separated by parting sheets.

Apart from the fluid entry and exit points to each layer the edges are sealed with bars that contribute to the structure's mechanical strength and contain the fluids, preventing them from leaking to the atmosphere.

This sandwich construction of layers continues in accordance with the layer stacking arrangement defined for the design until the heat exchanger block (or matrix) is complete.

The multi-stream capability of the BAHX is achieved by altering the entry and exit points of each process stream. It is possible for BAHX to have 10 different process streams, or more, in a single design allowing the process designer to optimize the cooling curves for maximum process efficiency.



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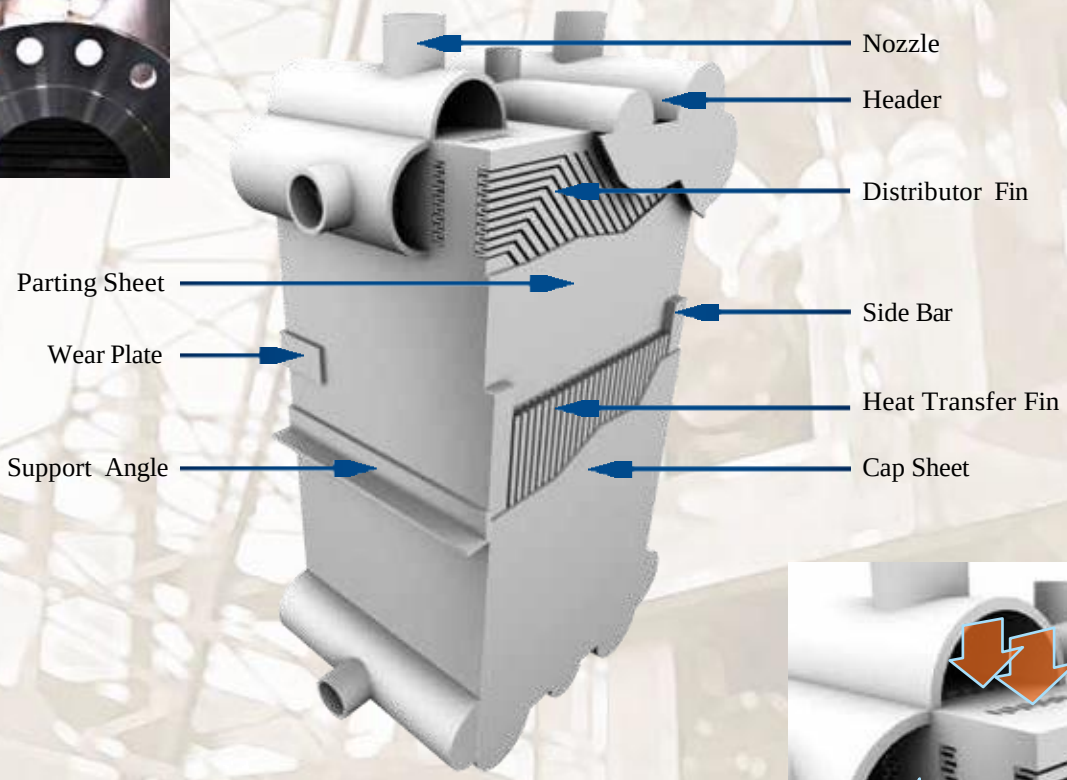
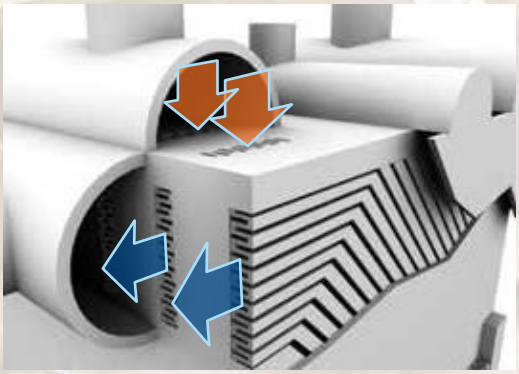
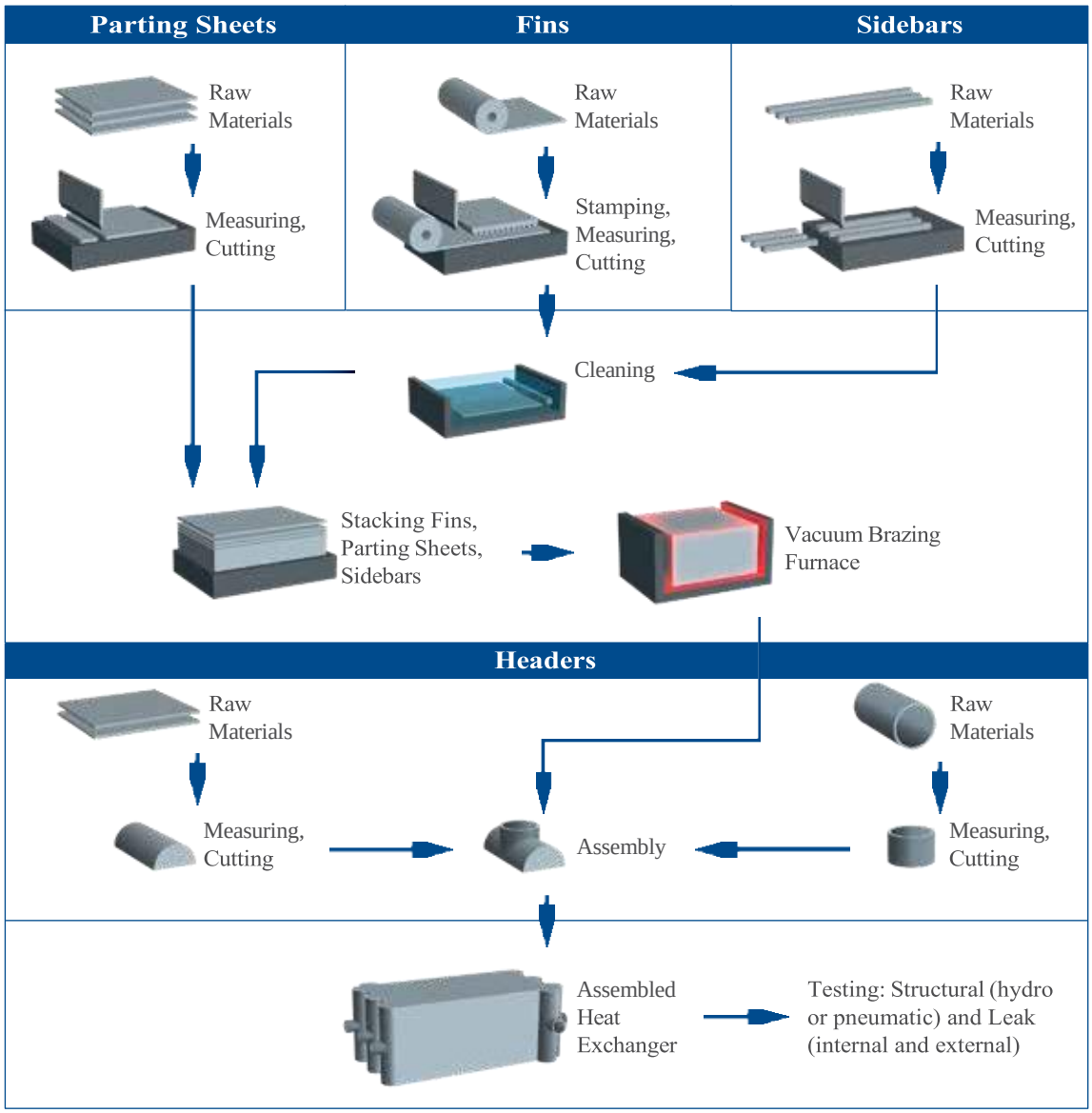




The matrix assembly is brazed in a vacuum furnace. The brazing process is highly complex and rigorously controlled to ensure a bond between each fin and corresponding plate. Even in a small heat exchanger that means millions of brazed joints. Each one is formed through capillary action as the brazing alloy on the surface of each plate melts during the high temperature operation and fuses to the parts in contact with it.

Following brazing, BAHX construction is completed with the welding of the header and nozzle assemblies over the fluid entry and exit ports. Support angles, pedestal base, wear plates, lifting lugs and other items that aid lifting, handling and installation are also welded to the unit after brazing.

From incoming raw materials to the shipment of finished product, all manufacturing processes are rigorously controlled and monitored to ensure total quality.



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Specialized Chart Expertise - High Pressure Capability

Chart currently offers BAHX in excess of 160 barg (2320 psig). Through a relentless research and development program Chart continues to expand the pressure limits and the maximum block sizes at which these elevated pressures can be reached. Chart boasts an experience list for high pressure BAHX which is unmatched by our competitors and is a demonstration of Chart quality and reliability.

Specialized Chart Expertise - Mercury Tolerant Construction

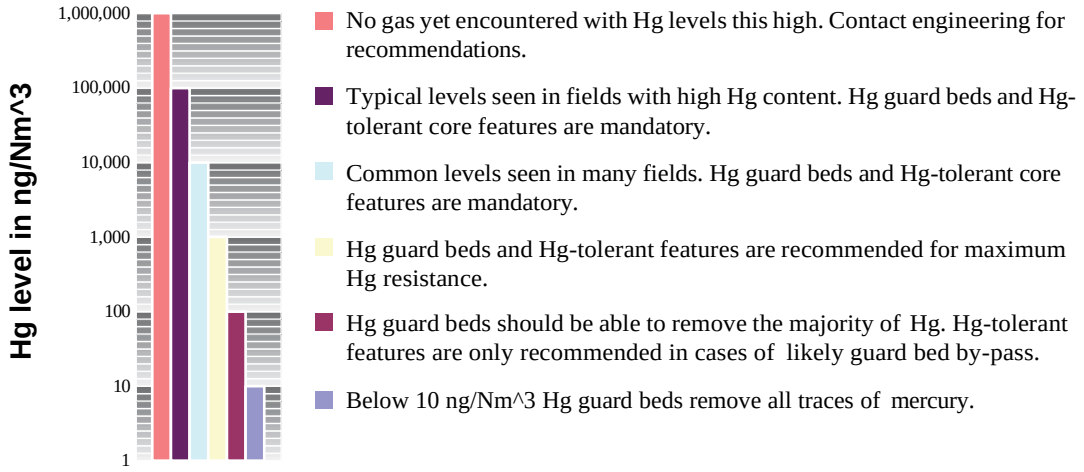
Under certain process conditions liquid elemental mercury can have severe detrimental effects on unprotected BAHX.

Chart was the first manufacture to identify and address the conditions where mercury contamination in the feed gas could be harmful to aluminum heat exchangers. Since introducing proprietary mercury tolerant features to our equipment we have continued to refine and supplement them to reaffirm our position as the reference standard for the industry.

Chart's proprietary mercury tolerant solution combines multiple design, material selection and fabrication features including:

- Preventative features against pooling of liquid mercury
- Elimination of crevices in the weld process where mercury can concentrate and attack susceptible microstructures
- Shielding of susceptible regions resulting from the weld process

Recommendations for Hg-tolerance features for different Hg levels in nanograms per NM^3



Since introducing mercury tolerant construction features in the mid 1980's there are hundreds of Chart built units in operation with no reported field failures.

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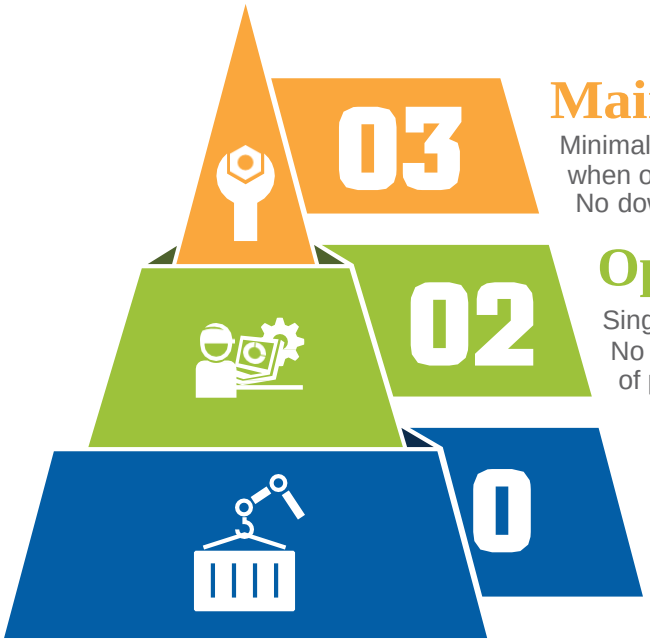
Specialized Chart Expertise - Cold Boxes and Manifold Assemblies

A Chart cold box is a complete process module that supports and houses BAHX and associated equipment in a single composite insulated package.

Externally a cold box is a carbon steel enclosure with flanged terminations at the box wall to facilitate quick and easy connection to process pipe work at site. Internally, a cold box can comprise:

- single or multiple BAHX manifolded in series and/or parallel
- inter-connecting pipework
- process and separator vessels
- instrumentation
- valves
- perlite installation

Chart's primary facility for assemblies and cold boxes is in New Iberia, LA, with direct access to the US intercoastal waterway and Gulf of Mexico.



Maintenance

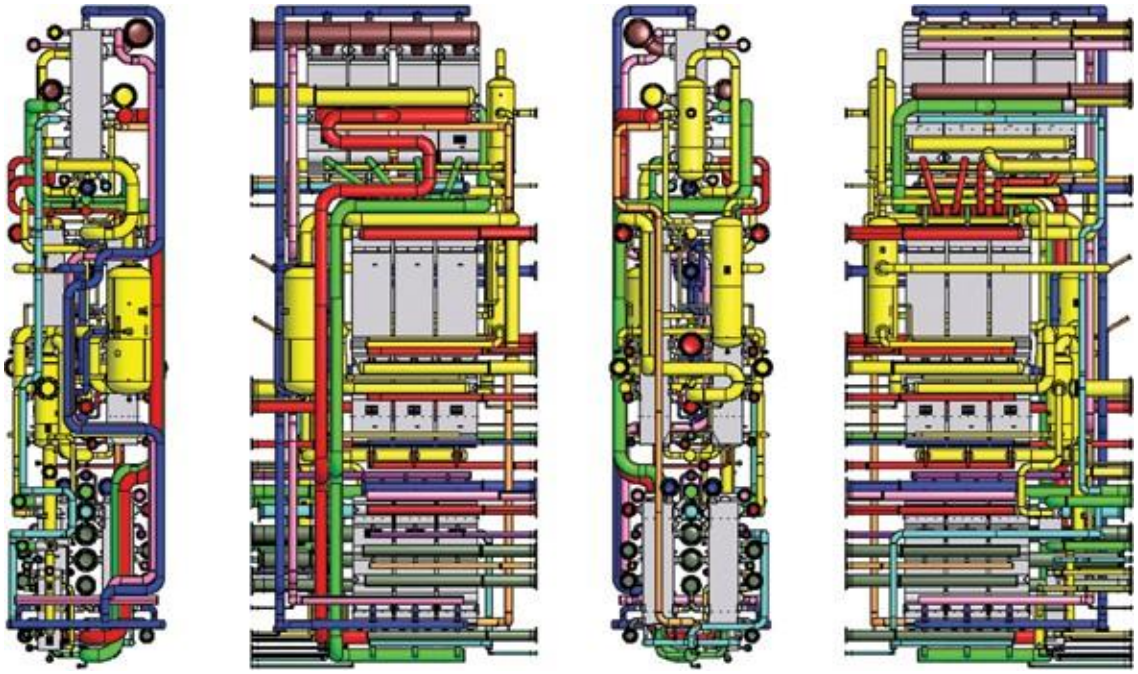
Minimal maintenance required when operated correctly. No down time = no lost profit.

Operation

Single point connections. No build-up of ice. Monitor & control of process through junction box.

Installation

Easy to transport & lift. Reduced on-site labor. Minimal on-site construction. Reduced overall project complexity.



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Specialized Chart Expertise - Core-in-Kettle® Heat Exchangers

Chart's Core-in-Kettle heat exchangers are designed to replace shell-and-tube heat exchangers with the direct benefits of lower installation costs, reduced operating costs, less replacement time and reduced horsepower requirements.

The high performance of Chart Core-in-Kettle heat exchangers will greatly improve the efficiency and economy of chillers, vaporizers, reboilers and condensers.

The Core-in-Kettle design is capable of achieving tight temperature approaches down to 2°F thereby increasing plant capacity and reducing horsepower requirements.

Enhanced performance through:

- Reduced temperature approach (down to 2°F/1°C) with resulting savings in power
- Up to 10 times greater heat transfer surface area per unit volume than conventional shell and tube units
- Multi-stream capabilities in a single construction

Cost savings through:

- Smaller vessels resulting in lower installation costs
- Smaller site plan, foundations and support structure
- Reduced refrigerant inventory
- Reduced process power requirements enabling a smaller compressor and lower operating costs

Applications

Petrochemical	Ethylene Propylene Ethane Butane Propane	C2, C3, C4 splitters Feed chilling train Heat pump distillation columns Columns Cascade refrigeration
Natural Gas Processing	Expanding plant LP-Gas NGL	Propane chillers Cascade refrigeration Liquid fractionation
Gas Liquefaction	LNG Nitrogen Hydrogen	Cascade refrigeration Feed chilling train

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Specialized Chart Expertise - Smart Layer®

Smart Layer® is a physical technology capable of providing early detection of end of service life for BAHX that is entirely passive from a plant operator's perspective.

Smart Layer is a predictive maintenance solution that provides advance warning when a critical threshold in the operational life of a BAHX has been reached. Excessive thermal gradients will weaken the unit's integrity and can lead to external leaks developing. Typically, because these operating upsets go un-noticed, the leaks manifest without warning. With Smart Layer technology the leak path is contained within the BAHX hence there is no loss of containment and an emergency plant shutdown is avoided. As well as containing the leak path, Smart Layer simultaneously triggers an alert to the plant control room that remedial action is required.

Standard BAHX in a Cold Box

- Operating Outside Guidelines
- External Leak
- Unplanned Shutdown

4 Weeks Production Loss:	$20,000,000
Repair Team:	$1,000,000
Rush Replacement BAHX	$2,000,000
Total:	**$23,000,000**

Smart Layer® BAHX in a Cold Box

- Smart Layer Alert
- Analysis
- Planned Repair/ Replacement

Repair Team & Analysis	$500,000
Replacement BAHX	$500,000
Total:	**$1,000,000**

Above example is for illustrative purposes only

By enabling plants to plan ahead for a unit's repair or replacement, the instances where unexpected external leaks cause unplanned shutdowns and expedited delivery of a replacement unit are significantly reduced, saving owners and operators millions of Dollars.

World Class Quality, Environmental & Safety Programs

Chart heat exchangers are typically designed, built, and tested according to ASME VIII Div. 1 code requirements, although Chart's global experience ensures compliance with all applicable international rules and regulations, as required.

ISO 9001:2015

ASME 'U'

National Board 'R'

National Board Registration

Chinese Mfr. License

Russian TR/CU 032/2013

DNV Mfg. Approval

Korean Mfr. Registration

ISO 14001:2015

ISO 45001:2018

Chart holds the following international HSE and quality certification:

- *Quality Management System in accordance with ISO 9001:2015*
- *Environmental Management System in accordance with ISO 14001:2015*
- *Occupational Health & Safety Management in Accordance with ISO 45001:2018*
- *Chart is fully compliant with the requirements of the Pressure Equipment Directive (PED) 2014/68/EU for the free placing of equipment on the European market without legislative barriers*

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After Sales & Support – Chart Lifecycle

Chart is committed to ensuring the optimized performance, longevity and safe operation of our equipment. We provide a complete suite of installation, operation and maintenance services to suit and the industry's fastest emergency response should the need arise.

Installation Services

- Installation of equipment
- Removal of old equipment
- Commissioning & start-up support
- Operator training

Cleaning Repair & Maintenance

Emergency Response

Plant Optimization

- Start-up/Operational process controls
- Process efficiency improvements
- Process analysis
- Training

DCS Analysis & Report Card Service

Field Service Engineer Site Visits

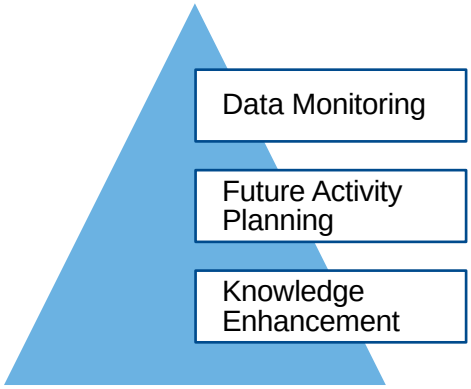
- Visual inspection
- Dye penetrant weld examination
- Borescope of unit internals
- Pressure testing
- Operator training

Exchanger Replacement Planning

Asset Integrity Management

Increased awareness and attention to operating data and process control will improve plant safety and reliability. Chart favors a proactive approach that mitigates the risk of plant downtime and the financial impact of lost production and revenue.

Asset Integrity Management (AIM) is a proactive preventative maintenance program that enables plant stakeholders to maximize the reliability and integrity of their assets. It combines multiple activities within 3 main pillars.



- Site visit by skilled personnel to evaluate the current health of equipment fleets
- Historic analysis of plant DCS to identify any operating patterns outside manufacturer's guidelines
- Continued analysis to mitigate against future non-ideal operating practices
- Corrective action recommendations
- Process optimization recommendations to support operational challenges
- Future event planning support, such as shutdowns and debottlenecking
- Operator training and education
- 24/7 emergency support

"An ounce of prevention is worth a pound of cure"

Benjamin Franklin

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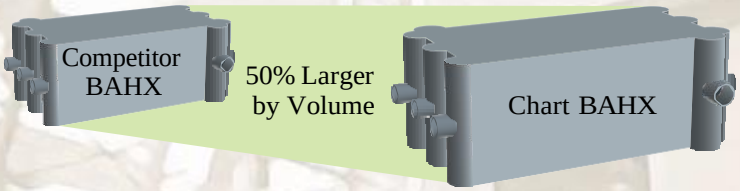
Operational Facilities

Since pioneering the development of large BAHX in the WW II era, Chart boasts a proud and unbroken tradition of engineering and manufacturing excellence at its principal facility in La Crosse, WI, USA.

At the heart of the manufacturing operation are the 4 vacuum furnaces, including the latest commissioned in 2018 as part of a multi-million Dollar capacity expansion, capable of brazing a single core at least 50% larger than the largest previously available.



- Greater heat exchanger efficiency and design optimization
- Reduced number of cores
- Reduced piping and overall footprint
- Reduced overall lead-time
- Eliminates welded modules
- Reduced CAPEX

Chart has a handpicked sales network in key territories throughout the world that supplement the headquarters by providing local expertise and product assistance.

Chart's manufacturing facility for cold boxes is in New Iberia, LA, and provides direct access to the US inter-coastal waterway and the Gulf of Mexico.

Experience Counts

>70	Years since Chart brazed the first large BAHX for an industrial application
>250	Chart fabricated cold boxes in service Chart BAHX with design pressure >1300 psig (90 barg) in service
>400	Chart Core-in-Kettle® in service
>800	Chart BAHX with mercury tolerant features in service
>1,500	Chart BAHX with design pressure >1000 psig (69 barg) in service
1982	Chart introduces vacuum brazing
1989	Chart manufactures the first Core-in-Kettle®
1998	Unification of Altec and Marston providing over 100 years combined BAHX design and manufacturing experience
2018	Major expansion at the La Crosse facility including the world's largest vacuum brazing furnace
>2,300	psig (159 barg). Chart's proven high-pressure capability
>13,000	Chart manufactured BAHX

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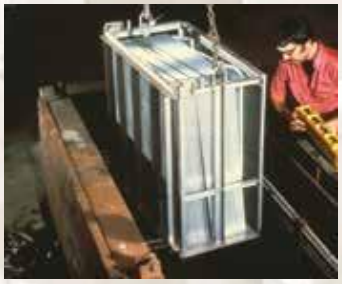
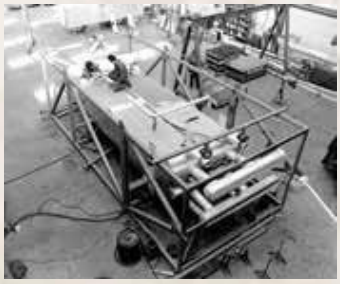
Dedication to the Core
70 Years of Manufacturing Heritage

A selection of images from our archives





General

	1 Cubic Meter of LNG	1 Metric Tonne of LNG	1 Cubic Meter of Gas	1 Cubic Foot of Gas	1 Million Btu	1 Therm	1 Gigajoule	1 Kilowatt Hour	1 Barrel Crude
Convert From:	Multiply By:								
1 Cubic Meter of LNG	1	0.405	584	20631	21.04	210.4	22.19	6173	3.83
1 Metric Tonne of LNG	2.47	1	1379	48690	52	520	54.8	15222	9.43
1 Cubic Meter of Gas	0.00171	0.000725	1	35.3	0.036	0.36	0.038	10.54	0.0065
1 Cubic Foot of Gas	0.00005	0.00002	0.0283	1	0.00102	0.0102	0.00108	0.299	0.00019
1 Million Btu	0.048	0.0192	27.8	981	1	10	1.054	292.7	0.182
1 Therm	0.0048	0.00192	2.78	98.1	0.1	1	0.105448	29.27	0.0182
1 Gigajoule	0.045	0.018	26.3	930	0.95	9.5	1	277.5	0.173
1 Kilowatt Hour	0.000162	0.000065	0.0949	3.3	0.003415	0.03418	0.0036	1	0.00062
1 Barrel Crude	0.261	0.106	153	5390	5.5	55	5.79	1612.9	1

Temperature

	Celsius	Fahrenheit	Kelvin
Convert From:	Multiply By:		
Celsius	1	F=Cx1.8+32	K=C+273.15
Fahrenheit	C=(F-32) / 1.8	1	K=(F+459.67) / 1.8
Kelvin	C=K-273.15	F=Kx1.8-459.67	1

Pressure

	Atmosphere	Bar	Kg/cm²	Kg/m²	Megapascal	Millibar	PSI (lb/in²)
Convert From:	Multiply By:						
Atmosphere	1	1.01295	1.03325	10332	0.10132	1012.95	14.696
Bar	0.9872	1	1.02	10197	0.1	1000	14.504
Kg/cm²	0.9678	0.9804	1	10000	0.09804	9.804×10^2	14.223
Kg/m²	9.678×10^{-5}	9.807×10^{-5}	0.0001	1	9.807×10^{-6}	0.09806	0.00142
Megapascal	9.86923	10	10.1972	101972	1	10000	145.04
Millibar	9.872×10^{-4}	0.001	1.02×10^{-3}	10.197	0.0001	1	1.45×10^{-2}
PSI (lb/in²)	0.068046	0.068948	7.031×10^{-2}	703.07	0.00689	68.948	1

Volume

	Cubic Centimeter	Cubic Meter	Cubic Inch	Cubic Foot
Convert From:	Multiply By:			
Cubic Centimeter	1	1×10^{-6}	0.06102	3.531×10^{-5}
Cubic Meter	1×10^6	1	61024	35.315
Cubic Inch	16.387	1.639×10^{-5}	1	0.00057
Cubic Foot	28317	0.02831	1728	1

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CHART®
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