Compact Platelet Heat Exchangers

HEXCES™

A division of Clean Energy Systems, Inc.

Innovative Thermal Management Solutions

Products

Heat Exchangers

HEXCES designs, develops, and manufactures thermal management systems to meet customer needs. Specifically, we focus on compact platelet heat exchangers, or CPHXs. These devices are used to transfer energy in the form of heat from one or more fluid streams to another without any mixing of the fluids.

Platelet technology allows for small fluid passages that provide maximum heat transfer surface area in an extremely compact space; increasing exchanger effectiveness while minimizing its weight and footprint. CPHXs can range from a few grams to multiple tonne assemblies.

All of HEXCES CPHXs are designed and built to ASME Boiler and Pressure Vessel Code Section VIII, Division 1.

Benefits of Compact Platelet Heat Exchangers

4 TO 6

Times **Smaller** and **Lighter**
Than Conventional Designs

600 BAR+

-200 TO 900°C

Materials of Construction

- Stainless Steel
- Nickel Based Alloys
- Cobalt Based Alloys
- Copper
- Titanium
- Refractory Materials
- And More

Multiple Fluid Streams Possible

- Gases, Liquids, and Two-Phase Flows
- Cross, Counter, and or Co Flow

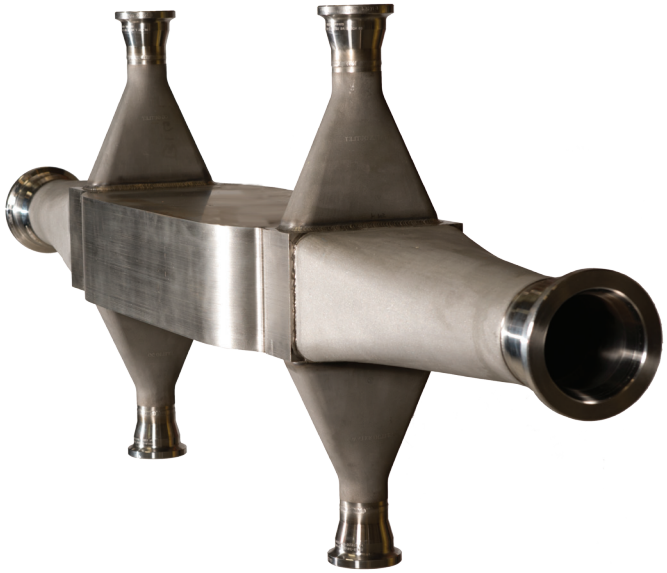
Thermal Effectiveness

- Unmatched Surface Area per Unit Volume
- High Heat Transfer Coefficients Achievable with Small-Hydraulic Diameter Flow Passages

HEXCES CPHX Examples

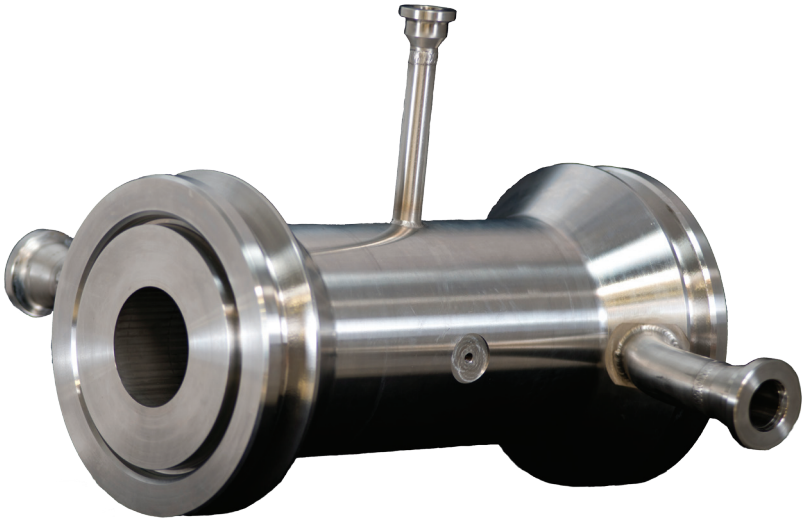
Superheater CPHX

Heat Rate – 0.5 MW
Working Temperature – 650˚C
Working Pressure – 100 bar
Core Dimensions – 29cm x 30cm x 15cm
Core Material – Inconel 600
Manifold Material – Inconel 600



Preheater CPHX

Heat Rate – 1.4 MW
Working Temperature – 300 ˚C
Working Pressure – 110 bar
Core Dimensions – 57cm x 30cm x 12cm
Core Material – 316L SS
Manifold Material – Inconel 600



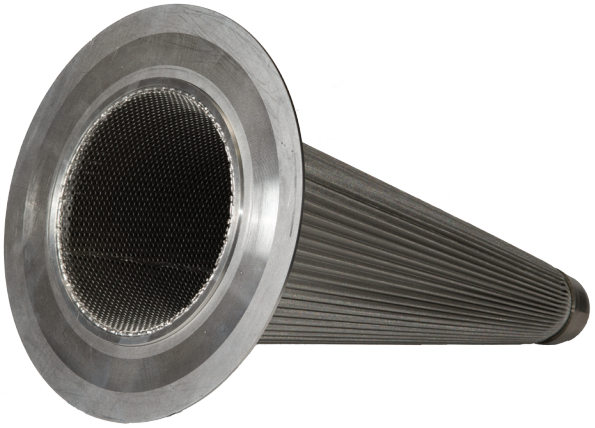
Formed Liner CPHX

Heat Flux - 13 kW/cm^2
Working Temperature – 1500 ˚C
Working Pressure – 110 bar
Core Dimensions – 10cm ID x 12cm OD x 54cm
Core Material – Inconel 600 / Hastelloy C22 Hot Gas Wall
Manifold Material – 316L SS

Filters & Strainers

HEXCES offers a line of filters and strainers, suitable for every CPHX application.

HEXCES CPHXs maximize heat transfer within a reduced footprint through the use of small cross section flow channels. To ensure product performance, system cleanliness and filtration are paramount. HEXCES works with customers to determine filtration needs for each application and tailors devices and procedures as necessary to assure superior performance and long life.



HEXCES Test Facility

The HEXCES test facility, wholly owned and operated by parent company Clean Energy Systems, is the world's largest pressurized oxy-fuel combustion test facility. The 40-acre site is laid out for R&D, sub-scale, and commercial-scale operations. Major features include:

- Dedicated Heat Exchanger Test Bed
- CES 20 MWt Oxy-Fuel Gas Generator
- CES 200 MWt Oxy-Fuel Gas Generator
- CES 30 MWe OFT-J79 Expander Turbine
- CES 150 MWe OFT-900 Expander Turbine
- SAGD Gas Generator and Steam Separator
- Full-Scale Steam Reheater Test Bed
- 100% Carbon-Capture-Ready, 5 MWe Steam Turbine Cycle;
  Suitable for Continuous Operations, Producing 1,500 Mscfd CO_2

Services

HEXCES offers a variety of services to assure quality, performance, and customer satisfaction.

- Applications Engineering
- Field Services
  - Installation & Commissioning Support
  - Product Inspection & Maintenance
  - Decommissioning Support
- New Product Development
- Performance Testing
- Repairs and Maintenance
- Systems Design Engineering

CHPX Installed in the HEXCES Test Facility

Markets

HEXCES provides innovative solutions for complex thermal problems across multiple markets.

Oil and Gas, On and Off-shore

- Gas Compression Coolers
- High Temperature Recuperators
- Inlet, Suction, Discharge, and After Coolers
- Liquefied Petroleum Gas Exchangers
- Natural Gas
  - Liquefaction and Regasification
  - Preheaters
  - Superheaters
- Synthetic Fuel Production

Power Generation

- Feedwater Heaters
- Fuel Gas Heaters and Preheaters
- Molten Salt Applications
- Organic Rankine Cycle Exchangers
- Pressurized Boilers
- Ultra and Super Critical CO_2 Exchangers

Aerospace

- Propulsion System Exchangers
- Satellite System Exchangers

Chemical Processing

- Mixers
- Reactors

Cryogenics

- Liquid Helium Exchangers
- Liquid Hydrogen Exchangers
- Liquid Natural Gas Exchangers
- Liquid Nitrogen Exchangers
- Liquid Oxygen Exchangers

Technology

Overview

The compact platelet heat exchanger (CPHX) utilizes platelet technology, developed in the aerospace industry. The resulting process allows the fabrication of monolithic structures containing complex and precise, 3D flow passages and features.

Platelet Technology

Platelet technology provides solutions to difficult thermal and fluid flow problems across a variety of market applications. The process begins with thin sheets of metal that are photo-chemically etched with specific design patterns to produce "platelets." Individual platelets are then accurately assembled, or "stacked," and joined via a diffusion bonding process. The result is a monolithic structure containing complex internal passages that allow for precise flow control, fluid manifolding and metering features. The diffusion bonding process effectively seals the passages between the fluid circuits with a solid metal barrier, isolating and segregating flows. This allows for much higher operating pressures and temperatures than achievable with traditional heat exchangers.

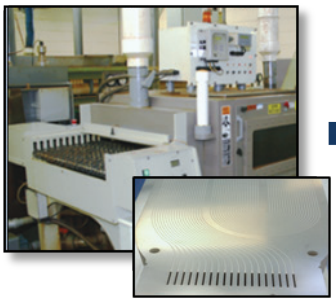
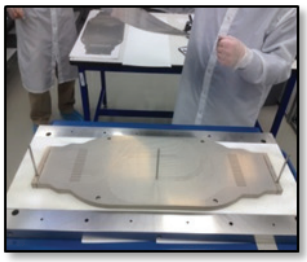
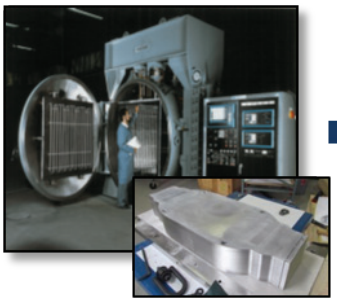


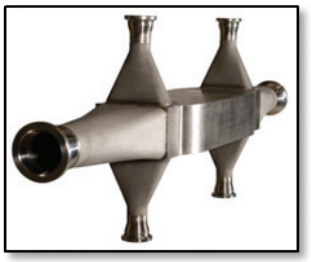
Photo-Etching Creates
Unique Platelet Designs



Platelets Accurately Stacked
in Clean Room Environment



Diffusion Bonding
Forms Monolithic Part



Secondary Operations
Complete Platelet Device

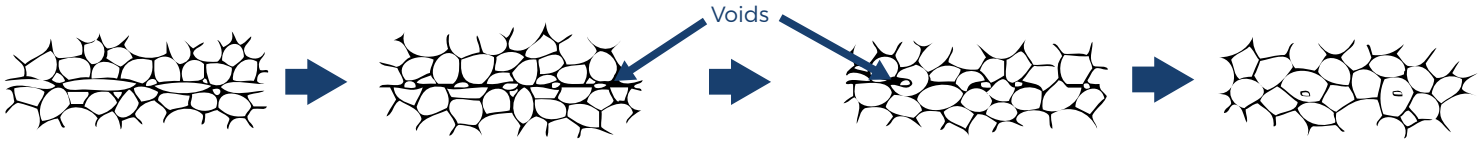
Stacking of CPHX platelets prior to diffusion bonding

Diffusion Bonding

Diffusion bonding is a solid state process, i.e. no melting takes place, that produces a monolithic joint through the formation of bonds at the atomic level.

The mating surfaces of the platelets are forced into intimate contact due to local plastic deformation at elevated temperatures; elemental diffusion across the platelet interface begins, along with grain boundary migration. At the completion of the process, all surface layers of the platelets are joined through inter-diffusion and the original interfaces and boundaries are fully coalesced, creating a singular device. When performed with HEXCES developed parameters, no macro-scale deformation occurs during the bonding process, leaving the as-fabricated platelet features intact with essentially parent material strength. These assemblies cannot be fabricated by any other current conventional or unconventional process.

Stages of Diffusion Bonding



Initial Platelet Contact

Plastic Deformation / Interfacial Boundary Formation

Creep Deformation / Boundary Migration

Volume Diffusion / Void Elimination

Micrograph of a diffusion bonded 300 series stainless steel part; the microstructure shows grain boundary propagation across the five platelet interfaces

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