CSI | eBOOK

A GUIDE TO CHOOSING THE RIGHT HEAT EXCHANGER FOR HYGIENIC APPLICATIONS

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CSI

INTRODUCTION

[Heat exchangers](#) come in a variety of designs for controlling temperatures in food, dairy, beverage, and pharmaceutical processing. Heat exchangers help processors maintain efficient operations for pasteurization, sterilization, clean-in-place and other hygienic operations.

This guide is designed for processors, production managers, and mechanical engineers to help in the heat exchanger selection process. We discuss three types of heat exchangers: plate and frame, shell and tube, and scraped surface. Depending on your application, each design has advantages and disadvantages and their own guidelines for maintaining peak performance.

PURPOSE OF HEAT EXCHANGERS

The purpose of heat exchangers is to transfer heat between two or more fluids to regulate temperatures during food, dairy, beverage, and pharmaceutical processing.

For example heat exchangers can help make products safe for consumption and extend shelf life by preventing growth of harmful microbes.

Heat exchangers are the heart of every pasteurizer system. They are designed to heat the product to a defined temperature at a specified flow rate. The product is then held at that temperature for a fixed period of time.

In some hygienic processes, ingredients must be mixed and heated to specific temperatures for proper mixing and activation on ingredients such as starches.

Finally, heat exchangers are designed to maximize heat-transfer surface area between fluids while also keeping pressure drop to a minimum.

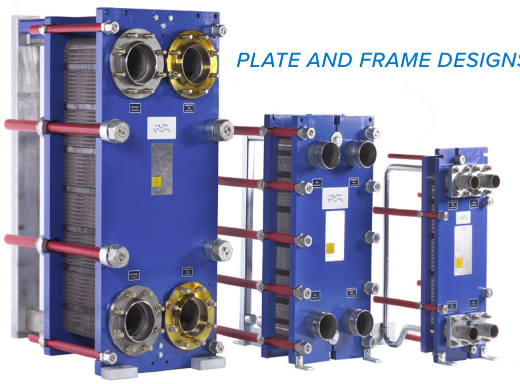


PLATE AND FRAME DESIGNS

SHELL AND TUBE DESIGN

SCRAPED SURFACE DESIGN

WHAT INDUSTRIES USE HEAT EXCHANGERS?

Food, dairy, beverage, and pharmaceutical industries all use heat exchangers as part of their hygienic processes. To meet regulatory requirements, processes must be carefully controlled to maintain proper temperatures for pasteurization, filling operations, and food safety.

Food, dairy, and beverage applications

Heat exchangers can help reduce or eliminate microbials to make products safe for consumption and to prevent spoilage.

Heat exchangers also heat or cool products during a variety of processing stages, including filling, cooking, and concentration. To meet processing requirements for products of varying viscosities, heat exchangers use innovative designs to meet unique process requirements.

For example, heat exchanger technology is vital to maintaining proper product temperatures in a variety of applications:

- Milk and cheese milk pasteurization
- Ultra-high temperature sterilization
- Beverage and energy drink pasteurization
- Standard and pulpy juice pasteurization
- Beer wort heating and beer cooling
- Liquid egg processing
- Bottled water treatment
- Soups, sauces, and starch heating
- Ketchup and mustard heating and cooling

Pharmaceutical applications

Pharmaceutical applications require systems that maintain precise temperatures for specific durations to ensure product safety and integrity. Heat exchangers are an effective method of thermal control in a variety pharmaceutical processes:

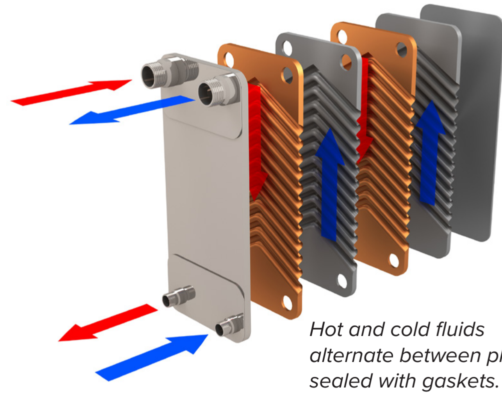
- Water-for-injection
- Temperature control for purified water
- Point of use coolers
- Pharmaceutical combining and mixing

In all industries where heat exchangers are at work, current technologies have several essential functions:

- Maintaining consistent temperatures for pasteurization
- Heating cleaning fluids that remove residues from systems components
- Transferring heat without contaminating products being heated
- Saving energy by re-using heated fluids to heat fluids in repeatable cycles
- Heating water for cleaning-in-place (CIP)

TYPES OF HEAT EXCHANGERS

PLATE AND FRAME

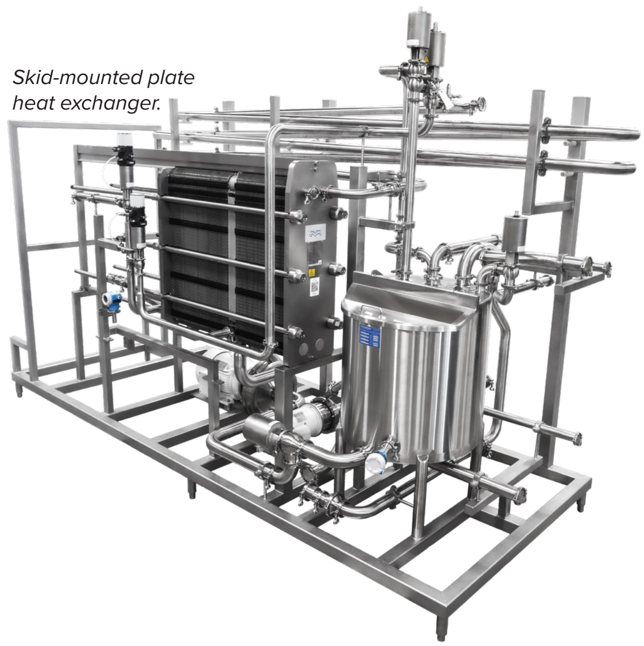


Hot and cold fluids alternate between plates sealed with gaskets.

Plate and frame designs include a series of corrugated parallel plates separated from each other by gaskets. Gaskets control the flow of hot and cold fluids over the plate surfaces, allowing heat to transfer from hot to cold fluids of low to medium viscosity.

Gasket plate and frame heat exchangers are among the most efficient designs so are also among the most common designs in processing systems. Gaskets between plates guide the flow of product and heating/cooling fluids through alternating channels. As hot fluids pass over the plates, heat transfers from the hot to the cold side, decreasing the temperature of the hot side and raising the temperature of the cold side.

Skid-mounted plate heat exchanger.



Key to efficient operations, heat exchangers must maintain sufficient fluid velocity across plates to transfer heat while also controlling pressure drops that can disrupt operation. Systems typically employ plate and frame heat exchangers for pasteurization, raw milk cooling, and CIP heating. Given their suitability for products with low to mid viscosity and few to no particulates, plate heat exchangers are commonly used for beverage, beer, wort, eggs, sauces, and most dairy processing.

Regenerative heating and cooling

In milk processing, chilled milk is heated from, for example, 4°C (39°F) to a pasteurization temperature of 72°C (162°F) and held at that temperature for 15 seconds and then chilled to 4°C (39°F) again.

Heat always transfers from warmer substances to colder ones, so during pasteurization, heat exchangers use heat from the pasteurized milk to warm the cold milk, which saves heating and refrigeration energy. The process is called regenerative heat exchange or heat recovery, typically reaching 90% and achieving up to 95% heat recovery from pasteurized milk. Recovery is lower for higher-fat products such as cream and ice cream mix. Regeneration has a positive impact on energy savings, cost of ownership, and efficient operation. Heat transfer occurs rapidly when the temperature differential is high. As temperature difference decreases, the rate of transfer slows down and stops altogether when temperatures equalize.

Operators can have multiple sections on one frame to control the flow of hot or cold fluids when products have to be heated in one stage and then cooled in the next stage.

For pasteurization, a multi-section heat exchanger uses connection plates configured by different corner connections for single, double, pass-through or blind channels.

Plate and gasket technology

The design of the corrugated plates creates a large but compact total surface area for transferring heat. The heat transfer area of the plates features a herringbone pattern that creates high turbulence which increases heat transfer and aids cleaning during CIP.

The plate distribution area ensures an even flow of fluid over the entire plate to maximize heat transfer. An optimized flow distribution also reduces uneven temperature zones that contribute to fouling.

While the narrow flow path of plate heat exchangers creates efficient heat exchange, the narrow path also limits its ability to process fluids to those with low to medium viscosity and few suspended particles that can result in fouling from particulates getting caught on plate contact points.

For fluids that contain particles, two solutions are available. Both allow particles to pass through while minimizing fouling:

- A low contact point, wide-stream plate that can run product with more particulate
- Wide-gap plates that can run more and larger particulate

PLATE AND FRAME = *VERSATILE*

Because plate and frame heat exchangers are designed to increase or decrease in capacity depending on application, they are among the most versatile heat exchangers available. They're designed for easy addition or removal of plates as requirements change.

In addition to variations in height and width that accommodate installation and system integration, plate and frame heat exchangers can scale in depth as system capacities change.

ADVANTAGES & DISADVANTAGES OF PLATE AND FRAME

ADVANTAGES

- Relatively inexpensive compared with other designs
- Excellent CIP-ability
- Easy to clean and maintain
- High heat regeneration
- High turbulence
- Replaceable gaskets
- Easy to increase/decrease capacity
- Smaller footprint than shell-and-tube designs

DISADVANTAGES

- Relatively low operating temperature
- Higher maintenance cost than tubular designs, due to gaskets
- Not for use with highly viscous or large-particulate fluids

TYPES OF HEAT EXCHANGERS

SHELL AND TUBE

Instead of transferring heat through parallel plates, shell and tube heat exchangers transfer heat between a bundle of tubes surrounded by a large shell vessel. Tubes enable processing of fluids that are more viscous or contain more particulate or larger matter. Fluids that run through the tubes exchange heat with fluids that run over the tubes contained by the shell.

Because the diameter of tubes is typically greater than the gap between plates in plate heat exchangers, shell and tube exchangers are suited to applications in which product is more viscous (resistant to flow), or contains high-density particulates. Maximum particle size depends on tube diameter. Tubular heat exchangers can typically run longer between cleanings than plate heat exchangers in ultra-high-temperature applications.

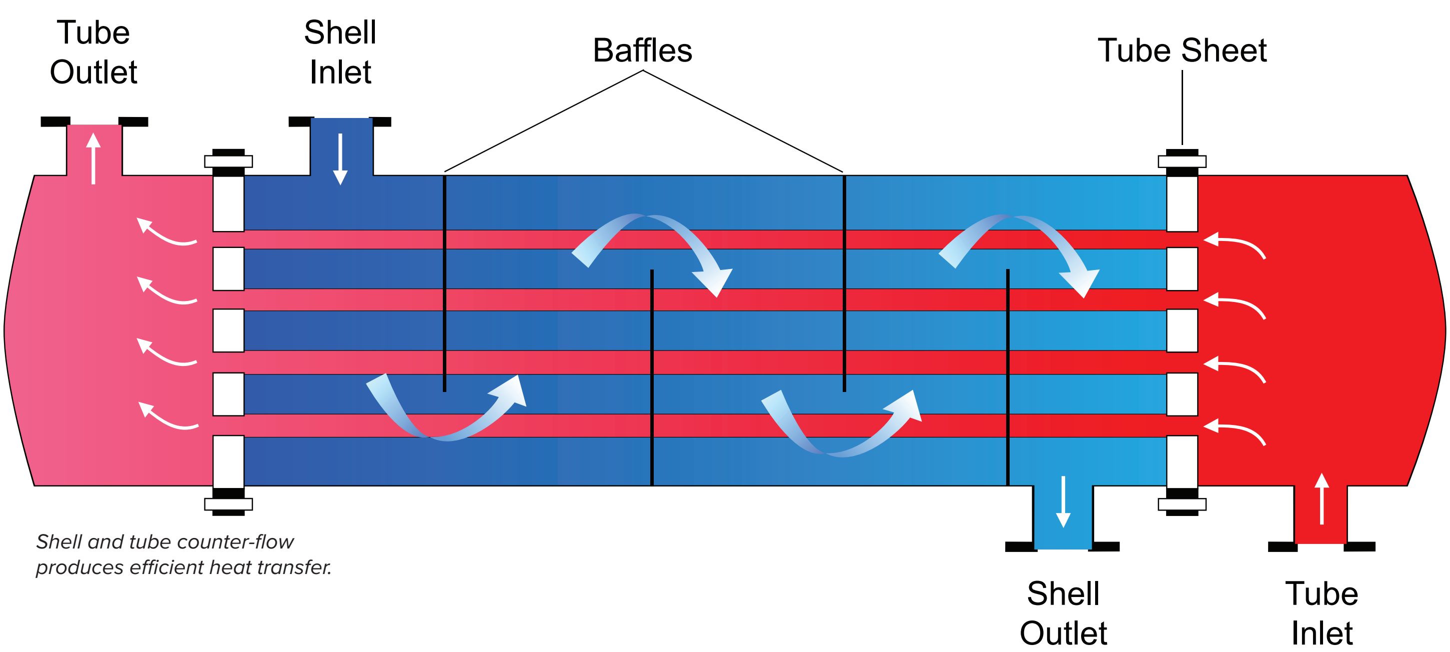
A concentric tubular heat exchanger features tubes of different diameters positioned concentrically inside of each other, which is especially efficient in heating or cooling because heating/cooling fluids flow on both sides of the product tubes. Product tubes can be sized to meet the requirements for viscosity and particulates. A concentric tube is especially suited to high-viscosity non-Newtonian fluids whose viscosity changes under pressure (shampoo, nail polish, ketchup).

As with other heat exchanger designs, shell and tube exchangers are set up to have product and heating/cooling fluids flow in opposite directions. For example, cold product fluid travels from right to left in the heat exchanger while the warming fluid travels from left to right over the product tubes. The counter-flow configuration takes advantage of maximized temperature differences for more efficient heat transfer.

One manufacturer's Pharma-line of shell and tube heat exchangers operates at pressures of up to 10 bar and operating temperatures of 150°C (302°F). Typical applications for the shell-and-tube heat exchangers include systems that process water (for injection or purification, for example), and CIP systems.

Double Tube Sheets

In pharmaceutical applications, the risk of mixing between product and the heating or cooling medium



Shell and tube counter-flow produces efficient heat transfer.

is eliminated thanks to a double tube sheet design. Product flows in the tubes while the service fluid flows around the tubes inside the shell. Service fluid is sealed in the shell by one tube sheet and a second tube sheet seals the product.

Heat exchangers with double tube sheets make leaks easy to spot because they appear at the joint in the outer tube plate. The heating fluid is sealed in the shell by the first tube sheet and the second tube sheet seals the product. In the event of a leak, the leakage of either fluid is easily visually detected. Shell and tube heat exchangers are especially effective in the pharmaceutical industry where product hygiene is paramount and demand for isolating products, purified water, and water for injection from heating/cooling fluids is especially high. To meet the industry's demands, high-quality tubular heat exchangers control microbe growth and prevent cross-contamination.

Some of the newest tube-in-tube designs for pharmaceutical applications feature high shear force and turbulence to maintain efficient transfer of heat while reducing bio-film.

Smaller, lighter-weight heat exchangers designed for tighter spaces can be effective substitutes for larger tube heat exchangers. They feature the same hot and cold fluid flows through alternating channels that create high turbulence for high heat transfer efficiency while using 50–80% less heat transfer area.

SHELL AND TUBE = *SIMPLE*

Simple, low-maintenance in-line heating option. While these units are widely used for viscous products with particulates in food, dairy, and beverage markets, they are typically found in pharmaceutical applications where complete drainability is required. Shell-and-tube designs are less efficient thermally, requiring more surface area and floor space. However, their designs can handle more and larger particulate, higher temperatures, and pressures than plate heat exchangers.

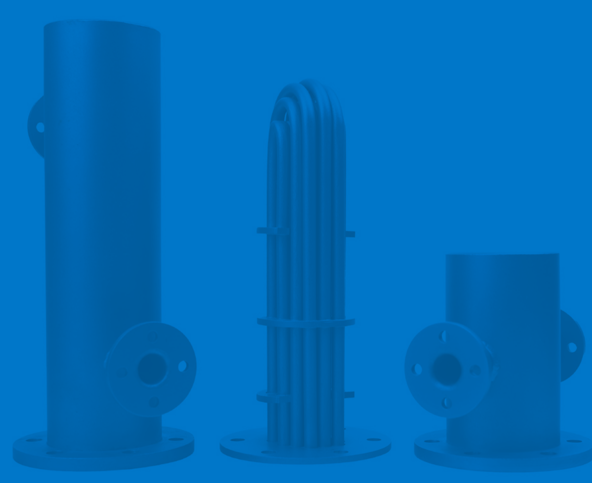
ADVANTAGES & DISADVANTAGES OF SHELL AND TUBE

ADVANTAGES

- Excellent CIP-ability
- Medium heat regeneration
- Lower maintenance cost than scraped surface designs
- For use with moderately viscous products or products with particulate
- Easy to spot leaks
- Relatively inexpensive compared with other designs

DISADVANTAGES

- Higher maintenance cost than plate heat exchangers
- Not for use with highly viscous products or product with large particulates
- Difficult to expand capacity
- Larger footprint than plate-and-frame designs



SCRAPED SURFACE EXCHANGERS

Some processes require heat transfer that prevents fouling from viscous and sticky products. In those processes, scraped surface heat exchangers are the right choice because of their ability to process fluids that include a high number of particulates or high viscosity. Scraped surface heat exchangers are often more expensive than other exchangers, but work more efficiently in some applications where other options would be ineffective.

In scraped-surface heat exchanger applications, the product enters the cylinder at one end and flows to the other end. Units may be positioned vertically or horizontally. The heating or cooling medium travels through a narrow ring-shaped (annular) channel.

Scraped surface heat exchangers are common in the food and personal care industries. Ensuring continuous production requires uniform heat transfer, but the consistency or content of some food products hinders efficient heat transfer. Scraped-surface heat exchangers meet the need for efficiency by keeping product off the walls and in the mix where it belongs.

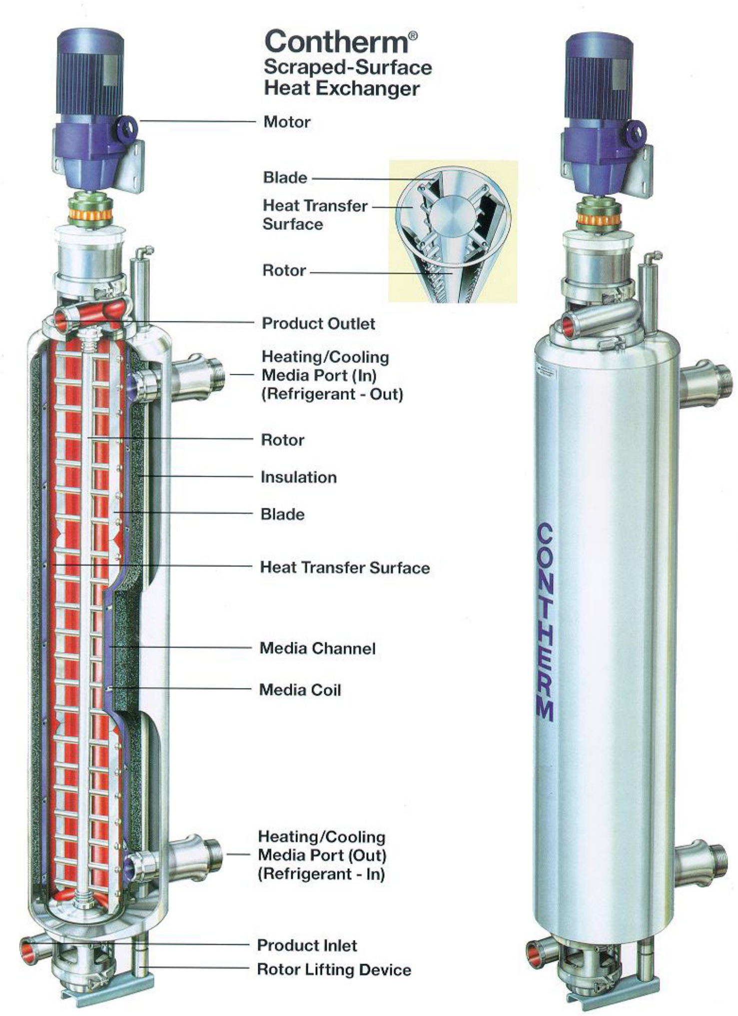
Typical processing applications:

- Ketchup
- Mayonnaise
- Spreads and fillings
- Sauces and puddings
- Baby food
- Skin lotions
- Shampoos

Scraped surface exchangers are fitted with rotating blades that remove product from the cylinder wall to maintain consistent heat transfer.

They're designed specifically for gentle product handling to avoid interference with product quality and consistency.

Scraped surface exchangers are typically mounted vertically. Inside, an electric motor turns a rotor fitted with scraping blades. To prevent damage to product, rotors and product move through the heat exchanger in the same direction, with product entering at the bottom and exiting at the top.



SCRAPED-SURFACE = *DOUBLE-DUTY*

Scraped-surface heat exchangers add value to systems by handling a wide variety of products. Phase changes are also possible, allowing evaporation to concentrate highly viscous products. Typical applications include processing of ketchup, mayonnaise, hummus, chocolate spreads, fruit pie fillings, gravies and sauces, whipped/aerated products, peanut butter, pizza sauces, puddings, salad dressings, and baby food.

Rotating blades continuously remove product from the cylinder wall to ensure uniform heat transfer. The product enters the cylinder in a corkscrew pattern in the same direction as the rotating scraping assembly. The design of scraped surface heat exchangers preserves product quality by providing gentler product handling. Both product flow and rotor speed can be adjusted to suit the properties of the product in the cylinder.

ADVANTAGES & DISADVANTAGES OF SCRAPED SURFACE

ADVANTAGES

- Very effective with viscous products or product with large particulate fluids
- High operating pressure
- Works in horizontal or vertical position

DISADVANTAGES

- Relatively more expensive than other designs
- Moderately CIPable
- Difficult to expand capacity
- No heat regeneration

Skid-mounted heat exchangers minimize equipment footprint.

CIP AND HEAT EXCHANGERS

In addition to heating processed foods, beverages, and pharmaceuticals, heat exchangers heat the water and chemicals used for CIP functions. CIP systems enable cleaning and sanitizing of processing systems to industry standards without requiring disassembly of system components. Accordingly, heat exchangers are also designed to be cleaned in place.

During CIP, the cleaning solution is pumped through the heat exchanger, where it is heated to the required temperature and where plate designs create turbulence that aids in plate cleaning. The solution is then routed to the target system and back to the circulation tank included in the CIP module.

After each cleaning phase, the cleaning solution is routed to a drain or back to the detergent tank for re-use. A normal sequence could include initial water rinse, lye cleaning, intermediate water rinse, acid cleaning, and final water rinse followed by chemical or hot water disinfection. The temperature, flow and detergent concentration in the CIP return line are automatically controlled throughout the cleaning cycle.

While performing their functions in processing and CIP, heat exchangers help reduce utility consumption by conserving water, electricity, and steam.

In all sanitary applications including pharmaceuticals and food processing, cleaning and sanitation must occur at sufficient intervals to prevent equipment fouling, reactions, and cross contamination. Temperature regulation is a key factor in maintaining temperatures during each interval.

CIP systems connect directly to heat exchanger connections and circulate a mixture of heated non-toxic cleaning agents that effectively remove scale, product deposits, and bio-fouling to clean process surfaces and restore performance of system components. Custom fabricated CIP systems are suitable for very large heat exchangers, which require expertly engineered CIP solutions.

Processing at high temperatures—with hard water or high pH levels—increases risks of fouling or scaling, so cleaning is required to maintain efficiency. CIP equipment circulates cleaning chemicals and rinses to flush interior surfaces of heat exchangers without having to disassemble them.

CLEANING AND MAINTENANCE

FOULING AND AGING

Degraded heat exchanger performance from fouling or aging results in extra operating and energy costs to compensate for gaps in the target temperature. Cleaning and maintenance of heat exchangers is therefore important to keeping systems running efficiently. Regular maintenance ensures equipment is in working condition and helps prevent emergency repairs. The cost of cleaning a heat exchanger is small compared to the cost of lost production should a heat exchanger require an unscheduled shutdown. Product or chemical deposits on heat-transfer surfaces lessen an exchanger's heat-transfer capacity and must be cleaned away regularly to maintain high performance and prevent disruption of processing.

Heat exchanger fouling, or the unwanted accumulation of deposits on heat-transfer surfaces, can result in several costs:

- Production loss from shutdowns
- Maintenance costs for removal of heavy fouling deposits
- Replacement of plugged equipment
- Increased pressure drops
- Decreased regeneration efficiency

TYPES OF FOULING

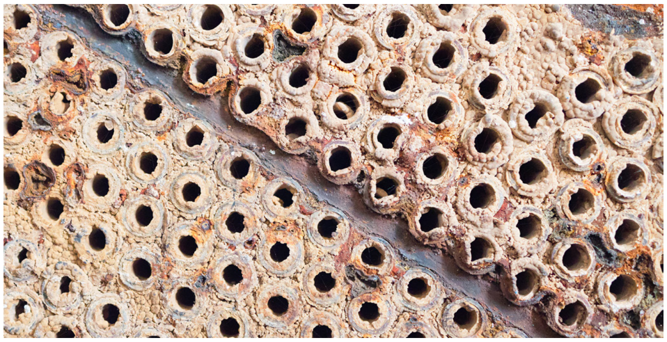
The most commonly occurring types of fouling and aging in hygienic processing fall into four main types:

Incrustation: The accumulation of a crust or coating of processed fluids, minerals, or cleaning agents on the surface of heat exchanger parts.

Scaling: A type of incrustation caused by calcium carbonate, calcium sulphate, and silicates.

Sediment: Comes from corrosion products, metal oxides, silt, alumina, and diatomic organisms (microalgae) and their excrement. Sediment accumulates because heat releases minerals and other particles from fluids during processing cycles, and those settle and deposit on heat transfer surfaces.

Biological growth: Sources of biological fouling include bacteria, nematodes, and protozoa.



Scaling on heat exchanger tubes

CAUSES OF FOULING

Fluid temperature

Water can produce scaling from minerals such as calcium carbonate (CaCO3). Salts deposit on the heat exchanger surface with increases in temperature. Similarly with increase in temperature during food processing, biological growth can occur.

Nature of the fluid

During milk processing, for example, fouling leads to a rise in pressure drop across the exchanger by reducing flow from the growth of deposits. In dairy industries, proteins, fats, sugars, and minerals from milk and dairy products can come out of solution, deposit on heat exchanger surfaces, and foul channels.

Fluid velocity

In most cases, fouling decreases at higher fluid velocities because increasing flow velocity increases the fluid shear stress, which causes more removal of deposits.

But for stronger deposits, increasing the flow velocity beyond a particular point may not decrease fouling significantly, and in the case of very strong deposits, increasing flow velocity may not have any effect.

CLEANING AND MAINTENANCE

WHEN TO CLEAN A HEAT EXCHANGER

You can tell when it's time to clean your heat exchanger when the exchanger doesn't achieve the correct product temperatures for heating or cooling. The incorrect temperatures result from plate surface fouling that reduces temperature transfer. So the answers to the question, "how often should heat exchangers be cleaned?" Is "often enough to maintain high performance."

You might also see pressure drops higher than specified because fouling is constricting the channel passage and increasing fluid velocity.

HOW TO GET RID OF FOULING

CIP equipment can clean fouling without disassembly. Using a combination of time, temperature and concentration, CIP provides both chemical and mechanical cleaning to the heat exchanger. If system configuration prohibits CIP, operators must perform manual cleaning.

CIP cleaning of heat exchangers typically includes several goals:

- Cleaning lime deposits
- Passivating surfaces to reduce susceptibility to corrosion
- Neutralizing cleaning chemicals before draining

THE IMPORTANCE OF FLOW RATE

The proper flow rate ensures effective mechanical action of fluids during cleaning. Some manufacturers recommend a minimum of 1 ft/sec velocity across heat exchanger plates, but requirements vary by manufacturer.

The flow rate during the cleaning of the product side should always be at least the same as the production's flow rate. An increased flow rate may be required in some cases—for example, in milk sterilization and the processing of viscous liquids or liquids containing particles.

BASIC CHEMICAL CLEANING PROCESS

Chemical cleaning in CIP offers several advantages:

- Quicker cleaning process
- Less labor intensity
- Cleans build up that can't be removed through mechanical action components

Operators typically follow four steps in the chemical cleaning process in CIP:

- Alkaline clean: removes build-up of organic materials
- Rinse: generally completed with a high-flow water flusher to remove loose debris and remaining residue from the alkaline step
- Acid cleaning: helps dissolve and soften fouling materials more deeply
- Final rinse

Recommended limits for cleaning solutions:

- 5% by volume caustic at a maximum 70°C (160°F)
- 0.5% by weight acid solution at a maximum of 70°C (160°F)

Manufacturers can provide more detailed information about cleaning and sterilization for specific equipment.

SELECTING THE RIGHT CHEMICALS

Using the correct chemicals for cleaning heat exchangers is important to ensure proper cleaning and to avoid damaging exchanger components. Cleaning agents must be compatible with both the plate metal and the composition of gaskets. For example, the following solvents and other cleaning agents can damage heat exchanger plates and gaskets:

- Ketones such as Acetone, Methyletylketone, Methylisobutylketone
- Esters such as Ethylacetate, Butylacetate
- Halogenated hydrocarbons such as Chlorothene, Carbon tetrachloride, Freons
- Aromatics such as Benzene, Toluene

Never use hydrochloric acid with stainless steel or titanium plates because the acid causes general corrosion, pitting, and stress corrosion cracking.

You should also never use water of more than 300 ppm of chlorine during the preparation of cleaning solutions. Chlorine, commonly used as a growth inhibitor in cooling water systems, reduces the corrosion resistance of stainless steels, including Hastelloy®, Incoloy®, Inconel®, and SMO. Chlorine weakens the protection layer of these steels, making them more susceptible to corrosion attacks than they otherwise should be. In every case where chlorination of non-titanium equipment cannot be avoided, you must consult your equipment supplier.

REPAIR AND MAINTENANCE

Repairs to heat exchangers typically refer to replacement of connection linings, bolts, plates, or frame parts. A regular schedule of maintenance can prevent the need for repairs.

To keep heat exchangers in good condition, regular maintenance is required. In addition to cleaning plates or other contact surfaces on a regular basis, gaskets must be replaced as needed to prevent leaks.

Regasketing

For clip-on gaskets, the regasketing process is as easy as taking the current gasket off and clipping a new one on.

For glued gaskets:

1. Remove the old gasket
2. Clean the sealing surface until it is free of foreign matter such as fat, grease or other soil
3. Check the new gasket and remove rubber residual before attaching
4. Clip on a new gasket or apply glue as required by gasket type
5. Perform heat treatment to set the glued gasket according to manufacturer's instructions

The new gasket is wrongly positioned if it rises out of the gasket groove or is positioned outside the groove.

Pressure testing must be performed by a person authorized according to local laws and regulations.

Hydrostatic leakage testing confirms the internal and external sealing function of the heat exchanger. The specialist tests one media side at a time with the other side open to the ambient pressure. In a multi-pass set up, all sections of the same side must be tested simultaneously.

Backflushing

Heat exchanger backflushing reverses the flow of fluids through the exchanger to flush accumulated material from the equipment. Processing typically creates debris such as mineral deposits from heated fluids, so backflushing dislodges the debris to keep exchangers running smoothly. One technique is to use a backflush valve for 30 seconds three times per day to reverse flow.

Heat exchanger monitoring

Heat exchange monitoring helps to keep the heat exchange system running effectively by reporting key variables that can affect performance or product integrity. These variables include:

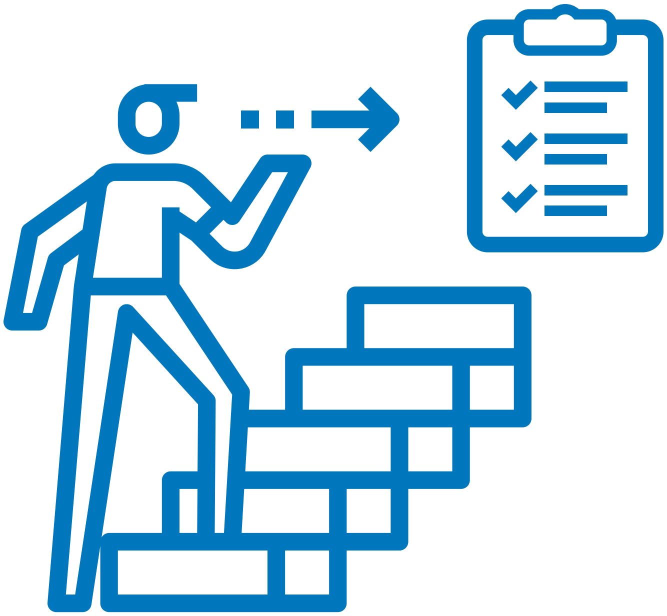
- Inlet and outlet temperature for cold fluid
- Inlet and outlet temperature for hot fluid
- Mass flow rates for both cold and hot fluids
- Pressure change across the heat exchanger for both hot and cold fluids

NEXT STEPS

Purchasing and installing heat exchangers for your processing facility is a considerable undertaking, requiring analysis, planning and above all, partners.

The best first steps

- Create a team of knowledgeable operators
- Create a team of managers from multiple departments
- Connect with a trusted company that has vast experience in designing and building process and CIP systems



Contact CSI for parts, repair and maintenance information, and a complete line of heat exchangers for hygienic processing. Our customer service team, engineers, designers, and product specialists provide solutions through a broad range of brands, technologies, and capabilities.

To speak with a Heat Exchanger or CIP expert, call 417.831.1411 or email sales@csidesigns.com