The heat exchanger is used to maintain a safe operating temperature or to capture heat. In this article, we will learn more about the heat exchanger, types of heat exchangers, and the working principles of heat exchangers. The formula for heat transferred from one system to a new one is

Q=m\*c\*ΔT

Where Q = Heat transferred, m = Mass, c = Specific Heat, and ΔT = Difference in temperature

What is a Heat Exchanger?

A heat exchanger is a device that allows the heat to be transferred from one fluid or medium to another. Liquids, gases, or solids of various temperatures can be used as the medium. The heat transfer process can be among two gases, two liquids, or one gas and one liquid. The fluids can be separated or in direct contact according to the type of heat exchanger. The heat is transferred between the two fluids because of their temperature difference without gaining or losing any heat from the surroundings.

Classification of Heat Exchanger

Heat exchangers are classified based on two different categories. The first considers the flow configuration within the heat exchanger, while the second is based on equipment type classification, primarily by construction.

The classification of heat exchangers are as follows:

Based on Flow configuration

Counter-flow heat exchanger: Fluids enter the exchanger from opposite ends in counter-flow heat exchangers and flow parallel to each other in opposite directions. It is the most efficient design because it allows the maximum heat transfer per unit mass.

Parallel flow heat exchanger: Both fluids enter the exchanger from the same end and flow parallel to each other in the same direction. Although less efficient than countercurrent flow, it provides more uniform wall temperatures.

Cross-flow heat exchanger: Both fluids flow perpendicularly to each other in this type of heat exchanger. They are somewhere in the middle of counterflow and parallel flow exchangers in terms of efficiency.

Based on construction design

Regenerative heat exchanger: The path flow in the regenerative heat exchanger consists of a matrix through which the hot fluid passes, first giving up its heat, and then the cold fluid passes through the same channel picking up the heat stored. Regenerators are primarily utilised in power plants and other energy-intensive industries for gas/gas heat recovery. Static and dynamic regenerators are the two primary types of regenerators. But these are not very common because they are typically used in specialised applications only.

Recuperative heat exchangers: Typically, a recuperator captures heat that would otherwise be lost. There are different kinds of recuperative heat exchangers classified into indirect contact, direct contact, and specials.

Heat Exchanger Types

The heat exchanger types are as follows:

Indirect Contact Heat Exchangers

Indirect contact heat exchangers use tubes or plates to keep the fluids exchanging heat separately. The types of the indirect heat exchangers are as follows:

Shell and tube heat exchanger: It consists of a cylindrical shell containing several tubes. One fluid passes across a bunch of metal tubes, while the other circulates via the surrounding steel shell. The fluid enters through the front end and leaves the exchanger through the rear end.

Plate heat exchanger: Plates are used to separate the fluids while exchanging heat in this. These heat exchangers are thin, slightly separated plates with large surface areas and small fluid flow passages for heat transfer.

Direct Heat Exchangers

Some examples of direct heat exchangers are steam injection used for heating fluids in pipelines with the help of condensation, Direct contact condensers, which are used as an alternative to tubular condensers because of the low cost, and direct heating, which can be used by passing hot air streams.

Working Principles of Heat Exchanger

Heat exchanger functions by transferring heat from higher to lower temperatures. Heat can thus be transferred from the hot fluid to the cold fluid if a hot fluid and a cold fluid are separated by a heat-conducting surface.

The operation of a heat exchanger is governed by thermodynamics. Heat can be transferred with the help of conduction, convection, or radiation. Conduction is the transfer of thermal energy from one material to another through the motion of a fluid such as heated air or water.

Convection is the transfer of thermal energy from one surface to another through the motion of a fluid such as heated air or water, and thermal radiation is a heat energy transfer mechanism characterised by the emission of electromagnetic waves from a heated surface or object.

The laws of thermodynamics are the fundamental concepts that underpin heat exchangers.

The Zeroth Law of Thermodynamics states that in thermal equilibrium, thermodynamic systems have the same temperature. If two systems are in thermal equilibrium with a third system, the two former systems must also be in thermal equilibrium with one another; hence, all three systems are at the same temperature.

The First Law of Thermodynamics states that energy cannot be created or destroyed, but it can be transmitted from one medium to another, such as heat.

The Second Law of Thermodynamics establishes entropy (S) as an additional property of thermodynamic systems, which describes a closed thermodynamic system’s natural invariable tendency to increase in entropy over time.

Conclusion

These principles collectively govern the working of the heat exchanger; the Zeroth Law establishes temperature as a measurable property of thermodynamic systems, the First Law describes the inverse relationship between a system’s internal energy and its surrounding environment, and the Second Law expresses the tendency for two interacting systems to move towards thermal equilibrium.

So, in the heat exchanger, a higher-temperature fluid (T1) interacts with a lower-temperature fluid (T2), directly or indirectly, allowing heat to transfer from T1 to T2 and move towards equilibrium. After the heat transfer, there is a decrease in T1 temperature and an increase in T2 temperature. Therefore, heat exchangers can be used to either heat a fluid or cool down the fluid.

Troubleshooting common issues in heat exchanger operations is crucial to ensure the efficient transfer of heat in various industrial processes. Here are some common problems you may encounter and steps to address them:

Heat Exchanger Design Handbook

1. Reduced Heat Transfer Efficiency:

- Insufficient Flow Rate: Check if the flow rates of the hot and cold fluids are within design specifications. If not, adjust valves or pumps to maintain the correct flow rates.

- Fouling: Inspect the heat exchanger surfaces for fouling, which can reduce heat transfer efficiency. Clean the surfaces by chemical cleaning, mechanical cleaning, or other suitable methods.

- Scaling: Scaling occurs when mineral deposits accumulate on heat exchanger surfaces. Use descaling agents or water treatment to prevent scaling.

2. Temperature Differences:

Handbook Of Plate Heat Exchanger

- Inadequate Temperature Difference (ΔT): Ensure that the temperature difference between the hot and cold fluids (ΔT) meets design requirements. If not, evaluate flow rates, fluid properties, or consider redesign options.

- Temperature Cross: In some cases, the outlet temperatures of the hot and cold fluids may inadvertently cross over. This can be corrected by adjusting flow rates or using appropriate controls.

3. Corrosion:

- Material Compatibility: Verify that the heat exchanger materials are compatible with the fluids being processed. Incompatible materials can lead to corrosion. Consider using corrosion-resistant materials or coatings if necessary.

- Corrosion Monitoring: Implement a regular inspection and maintenance schedule to detect and address corrosion issues early.

Inspection Of Shell And Tube Heat Exchangers

4. Leaks:

- Visual Inspection: Look for visible signs of leaks, such as puddles or damp spots around the heat exchanger. Address any leaks immediately to prevent further damage.

- Pressure Testing: Conduct pressure tests to identify and locate any hidden leaks. Repair or replace faulty components as needed.

5. Vibration and Noise:

- Mechanical Issues: Excessive vibration and noise can indicate mechanical problems. Check for loose components, damaged bearings, or misalignment and rectify them.

6. Insufficient Heat Transfer Area:

Process Design Of Heat Exchangers Pdf Document

- Inadequate Sizing: If the heat exchanger is not providing the required heat transfer, it may be undersized. Consider redesigning or adding additional units to meet the heat transfer demands.

7. Flow Distribution:

- Non-Uniform Flow: Ensure that both the hot and cold fluids are evenly distributed across the heat exchanger's surface. Baffles, flow distributors, or flow straighteners can help achieve uniform flow distribution.

8. Control System:

- Malfunctioning Controls: Verify the proper functioning of control valves, sensors, and instrumentation. Calibrate or replace faulty components as needed.

9. Safety Concerns:

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- Overheating: Install temperature and pressure relief devices to prevent overheating or overpressure situations that could damage the heat exchanger or pose safety risks.

10. Energy Efficiency:

- Optimize Operations: Continuously monitor and adjust the heat exchanger's operating parameters to maximize energy efficiency and minimize operating costs.

Regular maintenance, monitoring, and preventive measures are essential to keep heat exchangers operating efficiently and safely. Consult with experts in heat exchanger design and maintenance to address specific issues and ensure the long-term reliability of your equipment.

Heat exchangers heat or cool process fluids on the industrial scale. While there are several major types of heat exchangers, they typically have a few common safety hazards, all of which can be addressed through instrumentation. While this list is generic toward all heat exchangers, it can hopefully get the conversation started around heat exchanger safety and help engineers to identify hazards in their own systems. Many of these tips will also help ensure optimal heat exchanger operation.

Temperature excursions

Heat exchangers are often exposed to temperature extremes, both inside and outside of the system. Process fluids are often heated to high temperatures, while others, such as refrigerants, are kept extremely cold. Some heat exchangers are located outside, making them susceptible to temperature extremes based on the climate and geographic location of the plant.

The most common method of monitoring the temperature is to use thermocouples, though some heat exchangers use resistance temperature detectors (RTDs). The RTDs are typically used when tight temperature control is required, and when the temperature is not expected to change rapidly. At the very minimum, there should be four thermocouples: one to monitor the input and output streams of both process fluids. Additional sensors can be added throughout to understand how the temperature profile is changing through the process, or to search for areas of stagnant process fluid.

Phase changes

Perhaps the most important reason for keeping temperature in bounds is to prevent dangerous phase changes. While some heat exchangers are specifically designed for phase changes, many are not. For example, if the temperature climbs high enough to boil cooling water and turn it into steam, this will cause the pressure to rise rapidly. If the system is not designed for these high pressures, the results can be catastrophic.

Lower temperatures can also cause problems due to phase changes. Suppose an outdoor heat exchanger is designed for use in southern Florida. The company decides to relocate equipment to North Dakota and experiences freezing temperatures. As water freezes, it expands, which can rupture tubes in the heat exchanger. This can be particularly problematic for outdoor heat exchangers, as the temperatures may remain below freezing for months at a time, meaning the rupture may not be detected for a long time.

These phase changes can occur in mixtures, where one material boils off or freezes before another. At industrial scales, a cooling liquid that claims to be water free may have a few parts per million of water. The water may separate out and freeze, which may not sound like a big deal, but if the facility processes 300 million gallons of this substance a year, it adds up quickly.

It is worth noting that many refrigeration systems rely on boiling coolant to absorb waste heat, and these are built to withstand this phase change.

To detect phase change issues, a combination of temperature, flow and pressure monitoring must be performed. Adequate temperature monitoring will alert operators before the phase change occurs. Flow measurements can detect freezing by monitoring the flow rate before and after the heat exchanger. If the coolant is freezing in the heat exchanger, it will show up as a differential flow between the entrance and exit. Finally, pressure monitoring can detect boiling, but this should be thought of as the last layer of protection.

The problem with phase change excursions is how to deal with the chemicals in use, which will depend on the specific application. For example, water in danger of boiling can be relieved with a well-placed, appropriately-sized pressure relief valve. Flammable liquids that begin to boil should be sent to the flare instead of released into the open air.

In some cases, the chemical composition can be measured using any number of characterization techniques at sample ports before and after the heat exchanger. The composition of the material should not change as it runs through the heat exchanger; if it does, it might mean separation of a mixture.

Pressure excursions

Pressure excursions come from phase changes and from restricted flow. Phase changes have been previously discussed, but restricted flow can also raise the pressure. If a pump is pushing a process fluid into a heat exchanger, but the flow is restricted, the pressure will increase upstream of the blockage.

High pressure excursions can be detected by pressure gauges, obviously, but they can also be detected by flow meters on the inlet and outlet sides of the heat exchanger. The pressure drop across the heat exchanger under normal conditions should be documented, and if the pressure drop increases, it is possible that the flow is limited.

A high pressure excursion in a heat exchanger can be catastrophic, such as the Williams Olefins Plant. In this case, the heat exchanger ended up becoming isolated from its overpressure relief valve due to a design change that had not been properly vetted.

Low pressure can also be a problem if a pump is being used to pull the process fluid through the heat exchanger. Besides using a pressure gauge, the pump can be monitored for vibration or current draw. If the flow becomes restricted, the pump may draw more current. This can be detected by measuring current directly, measuring voltage drop across a shunt resistor, or indirectly with a proper selection of fuses or breakers. Also, the low flow can lead to cavitation on the input side of the pump. This can be monitored audibly or by using accelerometers to measure vibration signals.

Corrosion and fouling

How might a heat exchanger flow be restricted or blocked? The process fluids can corrode the surfaces they touch, leading to rust build up or scaling that can reduce the diameter of the tubes and restrict flow. Also, impurities in the process fluid can build up in low-velocity areas of the heat exchanger. For example, water that is being pumped from a nearby lake may have a small amount of sand and leaves, or a small amount of resin that is more dense and less viscous could collect in these areas as well.

The most effective prevention methods are to add filtering and purification of the process fluids. This will not capture all of the impurities, but it will reduce them, provided changing filters is added to the maintenance schedule.

When water is used, the measurement of the total dissolved solids (TDS) and pH can give an indication of the propensity for corrosion. If a record of TDS is kept over time, changes in water chemistry can be detected, which can indicate corrosion.

To mitigate corrosion, sometimes sacrificial anodes are placed in strategic locations. Often, these are a bolt with a plug of magnesium, zinc or another more electronegative metal. This can be easily forgotten, as it appears as a bolt head on the outside of the heat exchanger, but it must be checked and periodically replaced.

Leaks

Leaks can occur due to corrosion, mechanical damage, overpressure and other such conditions.

A leak between the tubes and the shell would be difficult to detect. Source: Saud/CC BY-SA 4.0

A leak between the tubes and the shell would be difficult to detect. Source: Saud/CC BY-SA 4.0

Leaks between the shell and the outside can often be spotted visibly, using periodic inspection or chemical “sniffers” for some chemicals. Acoustic sensors can be used to detect leaking vapor phase, such as steam, as the escaping vapor sounds different from the heat exchanger under normal operations. Shell leaks with a large temperature difference can be detected with thermal cameras as well.

Leaks between the inner surfaces can be much harder to detect, but very important to find. The two process fluids should not mix, and so a leak between the tube side and shell side in a shell and tube heat exchanger is not permissible. In the worst circumstances, these two fluids may react. At the very least, both process fluid streams will be contaminated. Worse than that, the leak may be difficult to detect.

To find a leak between shell and tube, flow meters can be placed on each stream. If the inlet side and the outlet side do not match, it could indicate a phase change, or it could indicate a leak between the shell and tube.

Summary

This list of issues is not exhaustive. The safest practice for evaluating heat exchanger surety is to start by performing a full Process Hazard Analysis (PHA) on the heat exchanger system, where all potential hazards are identified. This PHA should include engineers and both maintenance and operations technicians who are responsible for the system. Once all the hazards have been identified, appropriate instrumentation, Standard Operating Procedures (SOPs), Preventive Maintenance (PM) schedules and other safety and quality systems can be implemented.