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Sulfur Recovery

New Type of Chemical Reactor

Thermoplate Reactors for Sulfur Recovery

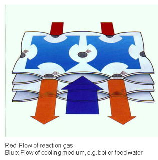
A new type of internally cooled reactor

…ave proved out in many applications. They are applied primarily …rous temperature control is required, or in reactions where the …perature dependant. Reactions of the first kind are especially selective oxidations and hydrogenations, as production of ethylene oxide, the second kind are e.g. the CO shift conversion or the methanol synthesis. So far typically straight-tube reactors were used for the purpose mostly with the catalyst in the tubes. For a few cases also spiral wound tubular heat exchangers were applied with the tubes submerged in the catalyst. However, these types of reactors had a number of features which are disadvantageous. Primarily often the heat exchangers' buildable geometry forced conditions on the catalytic reactions which were not optimal. For example the straight tube reactors had to be built slim and high in order not to have too high thermal stress on the tube sheets. That means necessarily high pressure drop, high linear gas velocity and mechanical stress on the lower catalyst particles. The spiral wound exchangers require many manufacturing steps and high skill and therefore typically are rather expensive. Both types of reactors cannot be built on site and therefore one must observe transportation limitations. This necessarily means also limitations for the throughput capacity. In view of the ever increasing plant sizes this aspect becomes increasingly important.

Now an innovative and proven type of plate heat exchanger, the so-called Thermoplate exchanger allows to optimize the reaction conditions with virtually no limitation to the geometry of the heat exchangers. A Thermoplate consists of two metal sheets welded together along their edges plus point-welded across their surface. This is done by robots which allows to produce a lot of exchanger surface at low cost. After that the plates are expanded by injecting high pressure liquid between the metal sheets. This opens channels as shown schematically in Fig 1. A plurality of Thermoplates is combined to form a heat exchanger package. That is then inserted in a shell which completes the heat exchanger. The main manufacturing steps are shown in Fig 2 to 5.

Between the Thermoplates the catalyst is embedded, within the Thermoplates flows the cooling medium, usually boiler feed water. Several Thermoplates are combined to form a heat exchanger module. A number of such modules are then combined to provide the total heat exchanger surface required. This may take place on erection site so that virtually any size of reactor can be realized, both with respect to diameter and height.

The new generation of catalytic reactors applies Thermoplate heat exchangers for temperature control of the reaction and is therefore called "Thermoplate Reactor".



Red: Flow of reaction gas
Blue: Flow of cooling medium, e.g. boiler feed water

Fig 1: Schematic depiction of a Thermoplate heat exchanger

Fig 2: Point welding Thermoplates

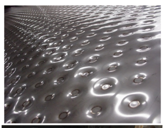


Fig 3: Thermoplate

Fig 4: Thermoplates with header

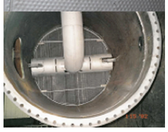


Fig. 5: Thermoplate in shell

Mechanical considerations

Dimensional accuracy
For catalytic reactions with a strong temperature change dimensional accuracy of the heat

exchanger for removal of the heat of reaction is of outstanding importance. Too big a distance from the next cooled surface could lead to hot spots and run-away of the reaction. Vice versa too small a distance may lead to too much cooling and thus too slow reaction and loss of product. These considerations of course are valid also for Thermoplate reactors. To ensure the predetermined distance of the Thermoplates from one another they are fixed at the edges by appropriate means which depend on size of the reactor, operating pressure and allowable pressure drop between different catalyst channels. The most simple method consists of just welding a sheet of metal to the edges. But there are also more sophisticated methods which are proprietary and patented.

Even more important than the accuracy at the edges is the distance of the Thermoplates over the whole surface. To ensure this manufacturing the Thermoplates with low dimensional tolerances is of course the most important precondition. For the purpose it is recommended to limit the size of each Thermoplate. For up to 5 m length and 1.5 m width less than 0.5 mm variation from the plane can be guaranteed.

For the dimensional accuracy of the reactor shell the tolerances for roundness according to DIN are adequate, i.e. no change to the normal manufacturing process is required there.

Mechanical forces in operation

Thermoplate modules are installed in the reactor with one fixed end and the other end free to float. In most cases the lower end is the fixed one. Thermal expansion is taken care of by a compensator in the pipe connecting the steam header to the pipe out of the reactor. Thus mechanical forces on the Thermoplates are kept to a minimum.

The forces due to the weight of the heat exchanger, the catalyst and the dynamic forces of the pressure drop in operation are transmitted by carrier beams to the reactor shell and the dished head ends. This keeps mechanical forces away from the Thermoplates themselves so that they do not interfere with their dimensional accuracy.

Installation of Thermoplate reactors

Smaller Thermoplate reactors are transported and installed on site as other types of reactors. For bigger units which transcend transportation limits the reactor shell may be supplied in pieces to the erection site and welded together there. The Thermoplate modules can always be designed small enough to be transported on trucks or railcars.

Installation of Thermoplate modules is done by inserting the complete module into a kind of drawer, very similar to the construction how honeycomb catalysts are built into a fluegas line of power plants. A crane lifts the modules into place. The connections for the cooling medium, usually boiler feed water and steam are flanged or welded to the respective headers. Flanging is preferable if for turn-arounds of the reactor the complete modules are to be removed. Welding is superior if exchange of the catalyst is planned with the modules in place in the reactor.

Every module has its own catalyst grid. This allows to fill the module with catalyst inside or outside the reactor. If filled outside the complete module plus catalyst is inserted. For exchange of spent catalyst the catalyst support grid is folded away so that the catalyst can flow out. To control the speed of catalyst flow the grids can be opened in small steps. This allows to handle the catalyst according to its individual features, as mechanical strength, dust deposits built up during operation, or pyrophoric chemistry. Also catalysts to be re-installed after external make-up need to be treated differently from catalysts which will just be sent to land-fill.

Modules may also be removed from the reactor for emptying and refilling. Of course this option is limited to non-pyrophoric catalysts. The flanges of the modules are opened and the modules then lifted out of the reactor. After that they can be emptied in a shop, refilled and either re-installed immediately or kept in a warehouse for fast re-installation at the next turn-around of the reactor.

Filling with catalyst and pressure drop distribution

For any major size reactor an even distribution of pressure drop over the cross section of the reactor is very important. To achieve this is rather easy in Thermoplate reactors. For not too sensitive reactions and robust catalysts, e.g. a CO-shift conversion one may just distribute it over the heat exchanger's cross section as one would do in a fixed bed without heat exchanger. For more sensitive applications the catalyst may be filled in by commercial machines which inject at a predetermined speed single catalyst particles. This ensures both even distribution of the catalyst and even density of the packing. This proved to be sufficient to meet requirements even of very sensitive processes.

Practical experience

When to apply a Thermoplate reactor rather than a tubular reactor

In Tab 1 the main features of Thermoplate and tubular reactors are listed for ease of comparison. From these features one can easily derive what the respective merits of a Thermoplate reactor and of a conventional tubular reactor are.

Tab.1: Features of Thermoplate versus tubular reactor

Thermoplate reactor	Tubular reactor
No tube sheets are required which lowers cost and eliminates thermal stress	Tube sheets required
More heat exchanger surface per m³ of catalyst is feasible	Up to approx 150 m²/m³ of catalyst
Heat exchangers can be assembled in modules. Mounting a reactor on site thus becomes feasible making independent of transport dimensions. This facilitates building of even very big reactors.	Modular set-up not possible. Reactor size limited by maximum transport dimensions
Reactor size independent of transport dimension limitations	Reactor size limited by transport dimensions
Easy filling with catalyst and emptying of spent catalyst. Reliable methods available for even catalyst distribution also for very big numbers of tubes.	Easy filling with catalyst and emptying of spent catalyst. Reliable methods available for even catalyst distribution also for very big numbers of tubes.
Keeping spare modules in the warehouse is a feasible option which further increases reliability	
Catalyst exchange may take place outside the reactor which reduces downtime. But exchange of catalyst with modules in place is also possible	Catalyst exchanges outside reactor no option
Each Thermoplate can be replaced individually if it fails.	Failed tubes can only be welded shut.
In most cases cheaper than tubular heat exchangers. But Thermoplates available only made of stainless steel.	Where CS applicable tubular exchangers may be cheaper
Available for operating pressures up to 150 bar on the cooling medium side. Outer pressure max appr 25 bar higher than cooling medium pressure	Available for any technically applicable operating pressure on both process and cooling medium side
Temperature resistance as typical for alloy steel	Temperature resistance as typical for carbon or alloy steel

These features make Thermoplate the reactor of choice for all those reactions which take place at

* moderate pressure up to 170 bar, but preferably up to 50 bar
* temperature up to 500°C, but preferably up to 350°C
* corrosive conditions require stainless steel up to Hastelloy. In non-corrosive applications carbon steel
  reactor may be cheaper.

Examples where Thermoplate reactors may be applied advantageously are acetylene hydrogenation in ethylene streams, ethylene oxide production, CO shift, Claus plants with sub-dew-point operation as the tailgas treatment. The biggest application though may be in Fischer-Tropsch synthesis, i.e. in the current GTL (gas to liquid), BTL (biomass to liquid) and CTL (coal to liquid) processes, both for the slurry phase and the fixed bed type of processes. In these applications Thermoplate reactors can be made a lot cheaper and at the same time more efficient than the conventional tubular reactors.

Examples of reactors built

In Fig 6 a reactor of appr 6 m diameter is shown. The task of this reactor is a proprietary selective reaction which requires a very stringent temperature regime. The operating company had so far applied straight tube reactors. After testing Thermoplates in detail the company decided in favor of the Thermoplates due to economic and operational reasons.

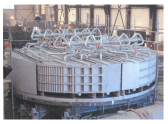


Fig. 6: Thermoplate reactor during assembly in the shop

For this reactor the modules of Thermoplates are shaped such that their edges reach to the shell. This facilitates the maximum heat exchanger surface per reactor volume. In Figs 7 and 8 a rather slim reactor is shown where the module of Thermoplates is in its own housing within the reactor shell. Only the shell bears the pressure of the process gas while the internal housing just serves the purpose of dimensional accuracy.

Fig 7: Thermoplate reactor in the shop

Fig. 8: Top view of a Thermoplate heat exchanger module

Conclusion

Thermoplate reactors are a new type of internally cooled catalytic reactor using Thermoplates to transfer the heat. This type of heat exchanger has been built already several hundred times and proved out especially where its resistance to fouling was required. Thermoplate exchangers can be built of modules which allows to set up the required exchanger surface by adding more modules, if necessary on site. This feature differentiates Thermoplates from tubular exchangers. With this option reactors of any size can be built, independent of the dimensional transport limits. So far reactors have been applied for fixed bed arrangements, as well as liquid reactions with suspended catalyst, and in sizes ranging from appr 1.5 m diameter to 6 m diameter. The reaction chemistry in all applications so far is proprietary know-how of the operating companies so that detailed process parameters must not be revealed.