As the market demand for hydrogen continues its growth, the economics in revamping becomes increasingly apparent. Factors such as short time to market, minimised investment, reduced downtime, small plot area and overall plant performance are typically highlighted during revamp studies. Satisfying all of these requirements with common revamp options is impossible. Only revamp options that are tailor made for such purposes will stand any chance in the attempt to fulfil the requirements of the market. This article describes Haldor Topsøe A/S unique heat exchange reforming technology and how heat exchange reforming can fulfil the demands of the H₂ revamping market.

**State of the art technology**
Haldor Topsøe’s unique knowledge and experience in the field of heat exchange reforming has its roots in the first commercialised heat exchange reformer (HER), which was released in 1985. The second generation of heat exchange reformers, the Haldor Topsøe Convective Reformer (HTCR), has been marketed by Haldor Topsøe A/S since the early 1990s, and counts more than 25 units covering the range from a few 100 Nm³/h up to 10 000 Nm³/h. The company’s third generation of heat exchange reforming is the Haldor Topsøe Exchange Reformer (HTER), which was developed in the late 1990s and demonstrated in full scale from the beginning of 2003.

**Figure 1.** HTCR concept.

**Figure 2.** HTER concept.
Both the HER and the HTCR are flue gas heated steam reformers. They are characterised by being very compact and by a high degree of internal heat recovery, making them highly efficient. The reformers are well suited as standalone units and as revamp options for capacity increase of existing plants.

The HTER is a gas heated reforming concept where the hot reformer effluent, at high pressure, is used as heating medium. The high pressure enables a more effective convective heat transfer compared with the HER and HTCR concepts. The HTER is well suited for capacity revamps and new units where factors such as efficiency, compactness and load following capacity are important.

Heat exchange reforming technologies

The HTCR consists of a tube bundle where each tube assembly consists of three tubes, a centre tube, a reformer tube and flue gas tube (Figure 3).

The flue gas from the combustion chamber passes through the flue gas annulus where heat exchange with the reformer tube takes place. The flue gas enters the flue gas annulus through the perforated part of the flue gas tube at approximately 1270 °C, and leaves through the top at approximately 600 °C. The process gas flows downwards through the catalyst bed at approximately 450 °C and reaches equilibrium in the bottom of the catalyst bed at 800 - 850 °C. The reformed gas then enters the centre tube and continues upwards. On its way up the reformed gas is cooled by heat exchange with the catalyst bed, resulting in an outlet temperature of approximately 600 °C. The reformed gas from all the centre tubes is collected in a common refractory lined outlet chamber from where it is transferred directly to a vertical boiler with integrated steam drum and circulation vessel for the flue gas waste heat boiler. This unique design effectively reduces the risk of metal dusting to a minimum while avoiding the implementation of very expensive metal dusting resistant metals. Metal dusting is a phenomenon that all heat exchange reformer technologies must consider thoroughly, as part of the materials will experience temperatures in the metal dusting range.

The HTER can be used either as a parallel (HTER-p) or a series (HTER-s) concept, or a combination of both (Figure 4).

In the HTER-s concept all the feed gas passes through the gas heated reformer, where it is heated and partly converted. The gas is then fed to the main reformer where final conversion takes place. The hot effluent from the reformer is cooled in the gas heated reformer and the sensible heat is used for reforming.

In the HTER-p concept the feed gas is split in two streams. One stream is sent to the main reformer where it is heated and converted. The other stream is sent to the gas heated reformer. The main part of the heat for the gas heated reformer is provided by cooling of the effluent from the main reformer. A part of the reaction heat will, as for the HTER-s and HTCR, be provided by heat exchange of the reformed gas with the catalyst bed.

The HTER is conceptually different in the way the catalyst is located. Traditionally the catalyst is either placed in the tubes or in the space between the tubes, most commonly with the catalyst in the tubes and the heating medium flowing on the outside. This is frequently referred to as ‘catalyst inside tubes’ (CATIT). This concept is very simple and well known.
from tubular steam reformers. The common and well proven alternative is referred to as ‘catalyst outside tubes (CATOT), where the heating or cooling tubes are placed in the bed.

A certain heat transfer area is required for a given heat transfer coefficient to transfer the required heat for the conversion. The heat transfer on the catalyst side is inherently high. The limitation for further increase on the catalyst side will consequently be pressure drop. For the CATIT concept the size and number of tubes is determined by the heat transfer area and the catalyst cross-sectional area for a given length. For the CATOT concept an increasing tube number with a correspondingly decreasing tube diameter results in the most compact unit. As an additional benefit the small tube diameter gives an increase in the heat transfer on the inside of the tube wall. The heat transfer can become as high or even higher than the heat transfer coefficient on the catalyst side, thus resulting in optimal utilisation of the available heat transfer area. However, as the tubes are long with a small diameter, catalyst loading becomes a problem and the tubes also become very flexible, rendering the full exploitation of the potential impossible.

The novel reactor design in the HTER overcomes these limitations by utilising a two bed system with catalyst on the outside and on the inside of the tubes. This design allows for optimal utilisation of the heat transfer area. The two bed system consists of a number of double tubes, as shown in Figure 5.

To obtain the same temperature profile in both catalyst beds, the heat transfer area to catalyst volume ratio is the same in the two beds. The heating medium flows in the annular channel between the two tubes, heating both the CATIT and CATOT side. The feed gas enters at the top and is split between the CATIT and CATOT bed. The gas is heated and converted as it passes through either of the beds. At the bottom the converted gas leaves the catalyst beds and is mixed with the hot reformer effluent. This gas mixture then flows in countercurrent through the annuli while heat exchanging with both catalyst beds. The temperatures in the HTER are strongly dependent on the available heating medium and also the specific application.

As discussed for the HTCR, metal dusting must be considered carefully. For the HTER, thorough material selection and testing in industrial applications have been successfully performed. Due to the optimal utilisation of the heat transfer area in the HTER, the application of the expensive metal dusting resistant materials is minimised. Inspection of industrial HTER applications has shown that the design and material selection in the HTER have effectively mitigated the metal dusting risk.

**Revamping with a HTCR**

As a revamp option the HTCR will be a very flexible solution. As it can be designed as a completely independent unit, the possibilities for tie-ins to the existing unit is almost unlimited, thus facilitating optimal reuse of capacity in the existing unit. The existing desulphurisation section will typically be reused, resulting in a branch out to the HTCR just before the existing

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**Table 1. Capacity increase by HTER-p installation**

<table>
<thead>
<tr>
<th></th>
<th>Before revamp</th>
<th>After revamp</th>
<th>Relative change</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ production (Nm³/h)</td>
<td>49000</td>
<td>61250</td>
<td>25%</td>
</tr>
<tr>
<td>NG feed consumption (Nm³/h)</td>
<td>18500</td>
<td>22500</td>
<td>22%</td>
</tr>
<tr>
<td>SMR duty (Gcal/h)</td>
<td>41</td>
<td>41</td>
<td>0%</td>
</tr>
</tbody>
</table>
reforming section. The existing reforming section and the HTCR will then be operated completely parallel. Tie-in to the existing unit will typically be done upstream the existing shift section. The cooling train and PSA of the existing unit are normally reused. The boiler feed water preparation system in the existing unit is reused. The HTCR allows the fuel balance for the complete system to be closed, without additional excess steam production.

This layout will result in a revamp package consisting of few pieces of equipment, namely an HTCR and a vertical boiler, but will yield a solution that allows for independent operation of the two reformer sections. The easy operation of the HTCR allows for fast and almost operator free adjustment of the plant capacity.

The onsite implementation of such a solution requires a minimum of downtime as basically only three tie-ins need be performed during a shutdown. The rest of the construction can be performed during operation of the existing unit.

With regards to overall plant performance after the revamp, the specific consumption figure will be decreased as the thermal efficiency of a HTCR is approximately 80% compared with a conventional reformer at approximately 50%. Figure 6 shows a schematic layout of a HTCR revamp solution.

Revamping with a HTER

Compared with the HTCR the HTER solution is completely integrated in the existing unit, resulting in an economically attractive and less plot area consuming solution. Using the HTER-s for revamping will inevitably lead to a significant increase in pressure drop. Although this may not be acceptable for capacity increase revamps, it is the obvious choice for revamps when the firing in the primary reformer is to be reduced or when feed and/or product pressures can be changed significantly. The HTER-p solution, on the other hand, does not increase the pressure drop in the main reformer. As the HTER must have a lower catalyst outlet temperature than the main reformer the conversion will be slightly lower than what is achieved in the main reformer. This can be counteracted by adjusting the S/C ratio and the inlet temperature to the HTER-p. This option allows for adjustment of the operating parameters to obtain the perfect balance between the size of the HTER-p and the combined product gas composition.

The integrated HTER solution results in an economically attractive and easy to operate unit. The flexibility when using the HTER-p solution is almost as good as for the HTCR solution and more economically attractive. A longer downtime compared with the HTCR must be accepted as the HTER is connected to the existing reformer.

The overall plant performance of the HTER revamp solution, as for the HTCR solution, will be better due to the characteristics of heat exchange reforming. Table 1 shows a typical set of data before and after a 25% capacity revamp. A typical layout of a HTER-p revamp solution is shown in Figure 7.

Conclusion

The innovative heat exchange reformer solutions developed and industrially demonstrated by Topsoe are the optimal solutions for boosting the capacity in existing hydrogen units. The flexibility, performance, cost and implementation time is unmatched by other revamping options.

The diversity of Topsoe’s heat exchange technologies allows for optimal utilisation of the existing plant capacity. Utilising the full potential of the existing unit along with implementation of cheap, compact and easy to use revamp solutions is the way to go when hydrogen capacity increase is on the agenda.