



Steam reforming solutions

Sandra Winter-Madsen and Henrik Olsson, Haldor Topsøe A/S, Denmark, describe new developments in steam reforming technologies and some solutions available for very large hydrogen production units.

The requirement for hydrogen in refineries worldwide is continuously increasing and very large hydrogen facilities are under design or construction in new grassroots refineries. There is a tendency for the single train capacity to exceed 200 000 Nm³/h of pure hydrogen, which presents new challenges to equipment sizes, reliability and operational flexibility. In addition, high energy prices and environmental restrictions on, for example, CO₂ emissions, entail increased operating costs. This article describes some of the new developments in steam reforming technologies and the solutions Topsøe offers for these very large hydrogen production units.

Several routes are available for hydrogen production, but the conversion of hydrocarbons is still the most economic route. Here the steam reforming process appears as the most common and feasible technology. Oxygen blown reforming, such as autothermal reforming or gasification, may only be feasible at very large facilities in connection with power production or production of chemicals¹.

Over the past 50 years, Topsøe has continuously focused on the development of new steam reforming technologies. This has resulted in more than 250 steam reforming units with Topsøe design. This article describes new developments in reforming technologies and their applications.

In recent years development of steam reforming technologies has focused on reducing the cost of the tubular steam reformer by using better materials for the reformer tubes and better control of carbon limits through improved catalysts. The cost of hydrogen production is improved, not only by lowering the capital cost, but also by selecting processes and catalysts, which allow flexibility by using low cost feedstock, and by selecting optimum process conditions giving low energy consumption. For large hydrogen plants, the cost of

feed, fuel and utilities is typically two thirds of the overall cost of hydrogen produced. The most energy efficient hydrogen plant operates at a low steam to carbon ratio and a high reforming temperature. By using Topsøe technologies and catalysts such as adiabatic prereforming, radiant wall steam reformer and medium temperature shift, the net energy consumption (NEC) figures can be reduced to 3.0 Gcal/1000 Nm³ hydrogen.

The development of the Topsøe high flux steam reformer (HFR) was initiated 10 years ago to reduce the size and the cost of the steam reformer. HFR also allows increased gas throughput per tube, which makes the HFR attractive for large hydrogen plants.

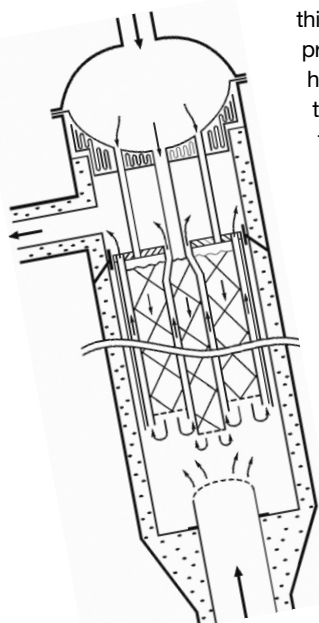


Figure 1. HTER concept.

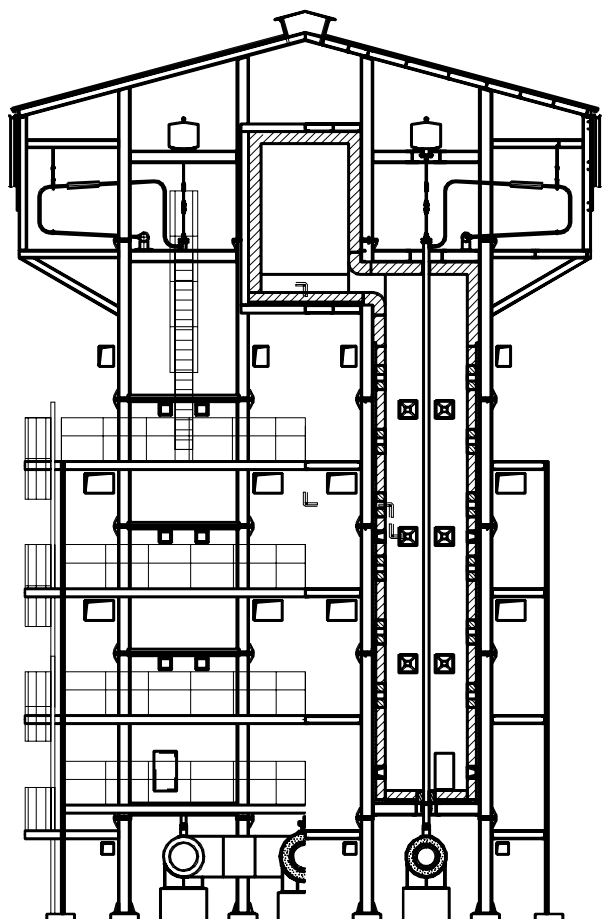


Figure 2. Schematic drawing of high flux reformer (HFR) and Haldor Topsøe exchange reformer (HTER).

Convection reforming technologies, such as the Haldor Topsøe exchange reformer (HTER), were developed to improve the energy efficiency in steam reformers. A schematic drawing of HFR and HTER is shown in Figure 2.

The combination of HFR and HTER reforming technologies are an energy efficient and cost effective solution for large capacity hydrogen plants. The following case study illustrate the operating cost advantages and environmental gains of this solution for a large hydrogen plant.

High flux reformer

The development of better tube materials and reforming catalysts combined with a better understanding of heat transfer and the influence of temperature levels and temperature gradients on tube life have made it possible to design and operate tubular reformers for tube wall temperatures up to 1050 °C. By controlling the tube temperatures along the length of the tube in a side fired radiant wall steam reformer, high average heat fluxes can be obtained without exceeding critical design values. The development of the HFR from pilot plant experiments, CFD simulations to industrial experience has been described². Today Topsøe radiant wall steam reformers are designed for operation at average heat fluxes close to double what was industrial standard 20 years ago (Figure 3). The high average heat flux leads to smaller reformer furnaces and higher gas throughput per tube, leading to lower capital cost per Nm³ of produced hydrogen. Topsøe designs steam reformers with average heat fluxes exceeding 100 000 kcal/m²h in hydrogen plants producing more than 200 000 Nm³/h H₂ in a single steam reformer.

Exchange reformer

Convection reformers were developed to improve the thermal efficiency of steam reforming, and Topsøe has developed two types of convection reformers: the process gas heated reformer HTER and the flue gas heated reformer Haldor Topsøe convection reformer (HTCR). In traditional steam reformers the thermal efficiency for the steam reforming process is 50%, and the heat in the flue gas is typically recovered for preheating feed streams and steam production. In hydrogen plants using HTCR technology, the thermal efficiency for reforming is increased to 80%, eliminating the export of steam. Hydrogen production using the HTCR technology has been used and proven industrially for more than a decade. This technology is preferred for smaller capacities up to 30 000 Nm³/h H₂ due to its compactness and modularisation³.

Table 1. Study results

Case	1	2
Feed consumption, Gcal/1000 Nm ³ H ₂	3.33	3.35
Fuel consumption, Gcal/1000 Nm ³ H ₂	0.34	0.14
Steam export, Gcal/1000 Nm ³ H ₂	0.66	0.40
Power consumption kW/1000 Nm ³ H ₂	16	14
CO ₂ emissions kg/1000 Nm ³ H ₂	900	860
Cost of feed, US\$ million/yr	33.29	33.50
Cost of fuel, US\$ million/yr	3.40	1.40
Electric power, US\$ million/yr	1.35	1.17
Steam credit, US\$ million/yr	-3.30	-2.00
Total annual operating cost, US\$ million/yr*	34.74	34.07

*Based on a NG price of US\$ 1.5/million btu, a steam price of US\$ 2.4/t and US\$ 0.05/kwh

The HTER technology was originally developed as a revamp option providing a capacity increase of up to 20 - 30%. The HTER technology has been in successful commercial operation since early 2003. The first HTER is operating at the Sasol Synfuels plant in Secunda, South Africa, and is producing synthesis gas equivalent to 30 000 Nm³/h of hydrogen⁴.

In new hydrogen plants, the HTER is used for boosting the plant capacity and for reducing the steam production⁵. For new grassroots hydrogen plants the advantages using HTER technology are lower fuel consumption, reduced steam export, increased single line reforming capacity and lower CO₂ emissions. These advantages are illustrated in the following case study.

Case study

Background

A client of HTAS was seeking an optimised solution for two very large (approximately 210 000 Nm³/h H₂ per train) grassroots hydrogen plants. As the client expressed interest in a layout that decreases the export steam flow compared to a traditional hydrogen plant, a combination of a HFR and HTER was considered a feasible option. Figure 4 shows the layout of the plant, in which the HTER is operating in parallel with the HFR.

Two cases were studied in order to evaluate the feasibility of this solution:

- Case 1: HFR.
- Case 2: HFR + HTER-p.

Case 1 is based on a large single HFR. The size and operating conditions are within the Topsøe design standards. Case 2 is based on a HFR and a parallel Haldor Topsøe exchange reformer (HTER-p). The operating conditions for both HFR and HTER-p are within Topsøe design standards.

From the results in Table 1 it can be concluded that the combined HFR and HTER solution (Case 2) is a more energy efficient layout than a single HFR (Case 1). Steam export is reduced by 40% and fuel consumption by 60%. The Case 2 layout provides savings on operating cost in cases where export steam credit is less than 70 % of fuel cost on an energy basis. In cases where export steam has little or no value, significant savings on operating cost will be achieved. Case 2 also features reduction of electric power consumption and CO₂ emissions compared to Case 1.

The investment cost estimates of the two layouts indicate that the capital cost is roughly the same with a small advantage for Case 2.


Considerations

As seen from the results in Table 1, a combination of HFR and HTER is an attractive option for hydrogen production when export steam has a low value and thus can be reduced.

The HFR reformer in Case 2 will decrease in size by 20% compared to the reformer in Case 1, also leading to savings in plot area.

The HTER reformer is easy to operate and does not require any additional facilities for startup, shutdown and emergencies. It is designed to follow the maintenance schedule and is loaded with the same type of catalyst as the HFR reformer.

Conclusion

The Topsøe HFR and HTER are industrially proven technologies developed by Haldor Topsøe to offer flexible and cost competitive solutions for hydrogen production. The combination of the HFR and HTER is applied in large scale hydrogen plants for minimising the production cost of hydrogen and is an environmentally attractive solution due to reduced emissions. 

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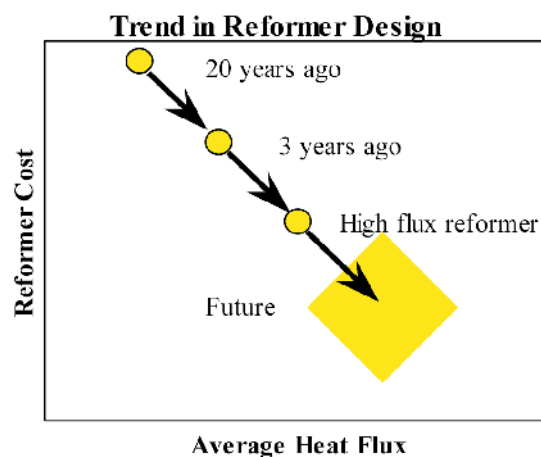


Figure 3. The trend in steam reformer design has moved towards higher average heat flux leading to lower cost reformers.

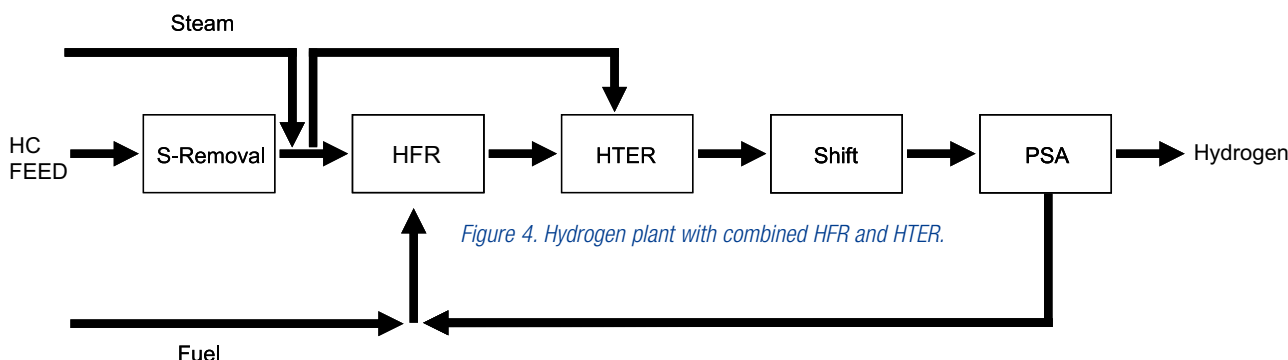


Figure 4. Hydrogen plant with combined HFR and HTER.

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