

## BorsodChem MCHZ, Czech Republic

### 6,000 Nm<sup>3</sup>/h HTCR Topsøe Hydrogen Plant A Case Story: 18 Months from Engineering to Operation



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## 1. Introduction

BorsodChem MCHZ chose the Topsøe HTCR hydrogen process in connection with an expansion of the production of amines in 2005. This case story describes the process from engineering to operation of the 6,000 Nm<sup>3</sup>/h Topsøe low-energy HTCR hydrogen plant at BorsodChem MCHZ's facilities in Ostrava in the Czech Republic. BorsodChem MCHZ and Topsøe's HTCR technology are introduced, and the engineering phase, fabrication, site installation, commissioning and operating experience of the hydrogen plant are described.

## 2. The BorsodChem MCHZ Company

The history of the BorsodChem MCHZ dates back to 1927 when construction of the first chemical plant, Moravské Chemické Závody, began in Ostrava in the Eastern part of the Czech Republic. In the beginning the production was related to inorganic fertilisers, coke and coke oven gas. Since the 1950's, the share of organic products has increased, and today amines and derivatives thereof constitute the backbone of the company's product range.

The company was privatised in 1992 and in 2000 when the Hungarian company BorsodChem bought a considerable part of the shares the name became BorsodChem MCHZ. Since the 1990's significant investments have been made in new production lines to match the change in product portfolio. BorsodChem MCHZ employs around 600 people at the plant in Ostrava.



Figure 1: Picture of the BorsodChem MCHZ complex

The products of BorsodChem MCHZ are used mainly in the polyurethane, rubber, pharmaceutical and food industry. Exports, particularly to Central and Western Europe, account for more than 75% of the total revenue and BorsodChem MCHZ is considered a major player on the international market for amines.

Hydrogen plays a major role in the synthesis of the various amine products, and in 1996 BorsodChem MCHZ started up the first hydrogen plant based on natural gas as feedstock. This hydrogen plant is based on conventional hydrogen technology from Haldor Topsøe with a side-fired tubular reformer.

Additional hydrogen capacity was required in connection with a recent expansion of the aniline plant. Even though the first hydrogen plant was operating satisfactorily, BorsodChem MCHZ was interested in the lower operating cost obtainable with a Topsøe HTCR hydrogen plant. Furthermore, the compact plant design and easy operation of an HTCR plant was attractive for BorsodChem MCHZ.

In January 2004 a contract for the supply of a 6,000 Nm<sup>3</sup>/h HTCR plant was signed between BorsodChem MCHZ and Haldor Topsøe. The contract covered the full hydrogen production process from natural gas to the pure hydrogen (>99.999%) exit of a PSA unit.

### 3. HTCR Process and Reformer Principle

The **Haldor Topsøe Convection Reformer (HTCR)** is based on the convection principle which allows for the design of very compact and energy efficient reformers. HTCR is the optimal choice for hydrogen requirements in the range of 5,000-30,000 Nm<sup>3</sup>/h hydrogen.

The HTCR process (Figure 2) uses feeds ranging from natural gas, LPG to naphtha which are processed in the following steps:

- Desulphurisation of feedstock
- Pre-reforming
- Convective reforming in an HTCR reactor
- Shift conversion
- Purification by Pressure Swing Adsorption (PSA)

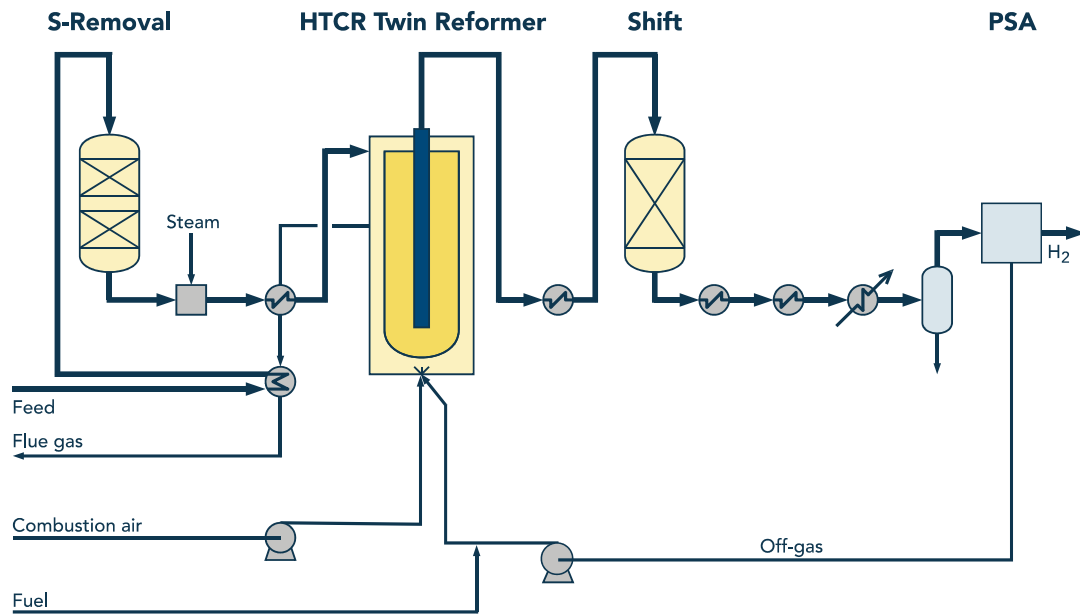


Figure 2: Typical layout of the HTCR process

The heart of the HTCR technology is the reformer which consists of a vertical, refractory lined vessel, containing the tube bundle with several tube assemblies. Below the vertical section is a horizontal combustion chamber containing a single burner.

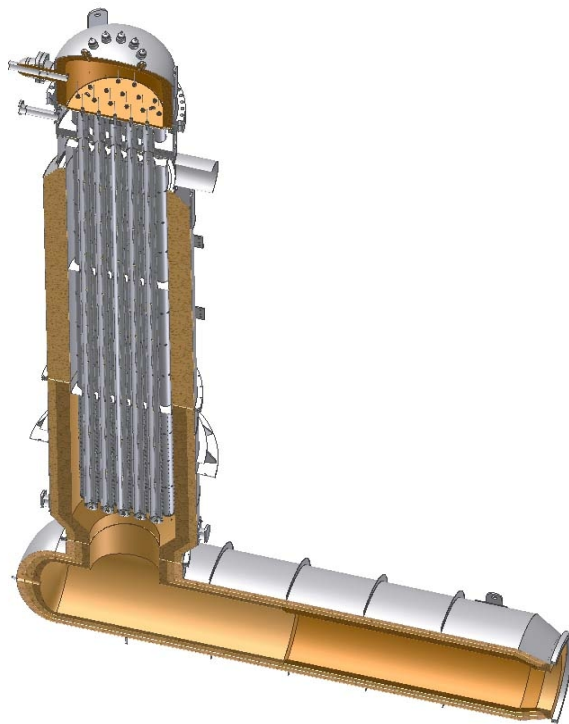


Figure 3: Cross section of an HTCR reformer

Each tube assembly consists of three tubes: Outermost is the flue gas tube where the heat flux is adjusted by a proprietary flue gas control device. As the flue gas flows upwards through the flue gas annulus, heat is transferred to the catalyst by convection. The catalyst is placed in the annuli between the reformer tube and the centre tube. The centre tube through which reformed gas leaves the reformer is inside the catalyst tube. Hereby the reformed gas is cooled on its way out, and the heat is passed on to the catalyst.

Due to the efficient convection heat transfer, savings on feed and fuel of up to 20 % compared to traditional reformer designs can be observed.

The convection principle allows for the design of compact reformers. The HTCR plant is to a large extent supplied as a preassembled skid-mounted unit minimising erection time and erection costs as compared to a traditional plant.

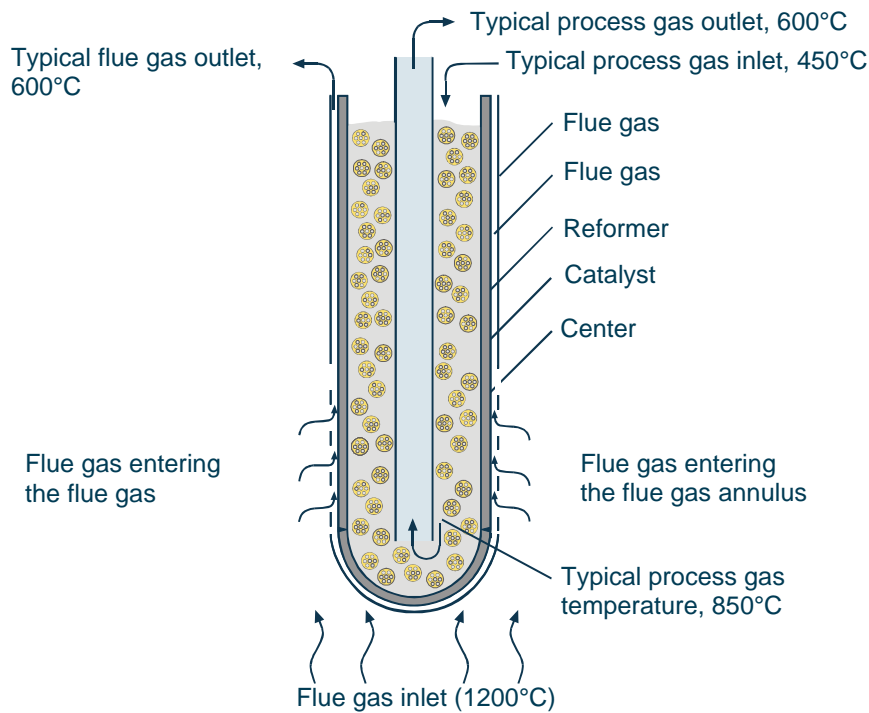


Figure 4: Principle of an HTCR reformer tube

#### 4. Engineering of the BorsodChem MCHZ HTCR Plant

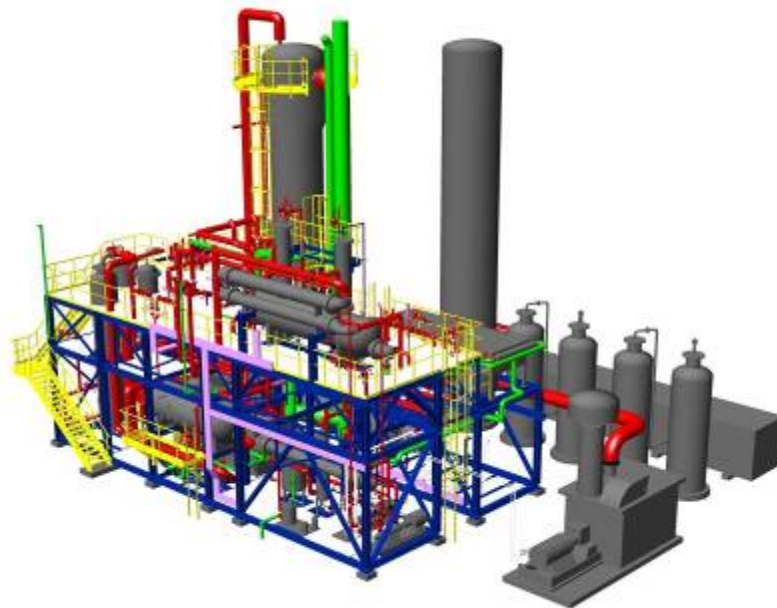
Topsøe started preparing the basic engineering package for BorsodChem MCHZ early in the year of 2004 including:

- Process flow diagrams
- P&I diagrams
- Plot plan
- Equipment and machinery specifications
- Instrumentation and electrical engineering

The layout was optimised for easy access to all parts of the plant while maintaining the small footprint made possible by the compact design of the HTCR unit. The plot area of the plant is approx. 18 \*25 meters.

During the spring of 2004 orders were placed for main equipment (tube bundle, burner, PSA unit, combustion air blower etc.).

A 3-D arrangement of an HTCR hydrogen plant is shown in Figure 5, illustrating the modular construction.



*Figure 5: 3-D arrangement of an HTCR hydrogen plant*

The hydrogen plant consists of:

- Prefabricated skids with vessels, heat exchangers, reactors, valves instrumentation, piping, cables etc.
- HTCR reformer with tube bundle
- Refractory lined reformer shell
- PSA unit with absorber vessels, off-gas drum and valve skid
- Combustion air blower
- Boiler feed water pumps
- Stack
- Ladders, platforms and a staircase

Topsøe established cooperation with a contractor in the Czech Republic who was awarded the contract for the detailed engineering, manufacturing and assembly of the skids in contractor's workshop and installation of the skids at plant site and pre-commissioning.

## 5. Workshop Skid Assembly and Fabrication of Equipment

Right from the beginning a very close collaboration was established between the Czech contractor and HTAS in order for the contractor to make the detailed engineering in the most optimal way. During the whole project engineers from Topsøe visited the contractor to follow the engineering phase. Later in the project phase, this cooperation ensured an efficient work flow during the assembly of the HTCR skids in the contractor's work shop and during installation on site.

The pictures in Figure 6 and Figure 7 show the progress during assembly of the skids in the contractor's workshop.



*Figure 6: Assembly of HTCR skids in contractor's workshop*

In the work shop the skids were fully assembled with vessels, heat exchangers, reactors, valves instrumentation, piping etc. For transport reasons the skids are subsequently separated by cutting the interconnecting piping.



*Figure 7: Assembly of HTCR skids in contractor's workshop*

Also the suppliers of Topsøe's proprietary equipment were visited frequently in order to follow the progress and ensure a high quality of manufacturing. Figure 8 shows the tube bundle during fabrication.



*Figure 8: Fabrication of the HTCR tube bundle*

## 6. Site Installation

Assembly of the skids in the contractor's workshop was completed in February 2005 and after cutting, the interconnecting piping the skids were transported to the site as illustrated in Figure 9.



*Figure 9: Transportation of skids from workshop*

Figure 10 shows the site during installation of the skids and illustrates the far from ideal winter conditions under which the installation started.



*Figure 10: Site installation of skids February 2005*

After installation of the skids, the inter-connecting piping between the skids was installed together with pre-fabricated piping, connecting the skids with the PSA, combustion air blower and BFW pumps. The pre-fabricated staircase, ladders and platforms were bolted to the skids. Also utilities (natural gas, demineralised water, nitrogen, instrument air and power supply) were connected to the skids.

Outside the skids, the combustion air blower, the PSA adsorber vessels, the PSA off-gas drum, the PSA valve skid and the stack were installed. Motor Control Center (MCC) and Control System (DCS) panels were installed, and the power supply to the various motors was pulled and connected. A number of loose delivered valves and instruments were mounted and wired to the DCS which was installed and implemented in the control room.

The refractory-lined HTCR shell was mounted on the burner chamber in the skid structure and the HTCR tube bundle was placed in the shell (Figure 11).



*Figure 11: Installation of HTCR tube bundle April 2005*

The plant was mechanically completed at the beginning of May 2005 after which pre-commissioning activities took place.

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## 7. Pre-commissioning

During May 2005 pre-commissioning was carried out including the following activities:

- Cleaning and flushing of piping and boiler
- Check of electrical systems and instrumentation
- Check of control system
- Check of rotating equipment
- Catalyst loading
- PSA adsorber loading
- Leak testing
- Initial start of burner system
- Functionality test of various equipment

## 8. Commissioning and Test Run

Start-up of the plant was initiated at the beginning of June 2005.

The start-up procedure is easy and very straightforward. Heating of the reformer section is done by once-through nitrogen whereas the desulphurisation section is heated up in natural gas. Once the required temperatures in the reformer are achieved, nitrogen is replaced by steam and natural gas and operating conditions are adjusted towards design. When the capacity reaches 30 %, the Load and Temperature Management (LTM) system incorporated in the control system will automatically adjust the capacity to the required level. Since all heat input is supplied by just one burner, the plant responds very fast to changes in hydrogen requirements.

The initial start-up was very smooth, and the reformer refractory was slowly dried out following the prescribed temperature curve.

When the load was increased towards 100 %, it was seen that the burner flame was not stable at high rates. A design error in the burner nozzle made by the burner supplier was detected. Until a re-designed burner nozzle was fabricated and installed at the beginning of August 2005 the plant operated at 80 % capacity. After the replacement of the burner nozzle, the burner has been operating exactly according to specifications in the whole capacity range.

A 72-hour test run was carried out in September 2005. Production and consumption figures achieved during the test run are given in Table 1.

Plant Capacity	100%
Impurities in hydrogen:	
<ul style="list-style-type: none"> <li>• Nitrogen</li> <li>• CO</li> <li>• CO<sub>2</sub></li> <li>• CH<sub>4</sub></li> </ul>	<ul style="list-style-type: none"> <li>• 3 ppm vol.</li> <li>• 0.3 ppm vol</li> <li>• 0.0 ppm vol.</li> <li>• 0.0 ppm vol</li> </ul>
Natural gas consumption, feed + fuel	2,475 Nm <sup>3</sup> /h 3.55 Gcal/1,000 Nm <sup>3</sup> hydrogen
Demin. water consumption	3,666 kg/h
Power consumption	314 KW
Cooling water consumption	24 m <sup>3</sup> /h

*Table 1: Test run operating data*

The data from the test run met or outperformed the flow sheet figures and confirmed the high energy efficiency of the HTCR plant. Due to initial problems with the PSA switching valves, the HTCR plant was only formally accepted by BorsodChem MCHZ following a new test run in December 2005 after rectification of the PSA valves.

## 9. Operating Experience

BorsodChem's HTCR hydrogen plant has now (October 2007) been in operation for 28 months.



*Figure 12: Plant in operation June 2005*

The HTCR plant has operated practically continuously at 100 % capacity except for a few scheduled shutdowns and a handful of unscheduled shutdowns caused by factors not related to the HTCR plant. One of the shutdowns related to the before mentioned rectification of the PSA valves.

It should be noted that BorsodChem MCHZ has maintained the existing number of operators as each shift of two operators now operate both the existing hydrogen plant and the new HTCR hydrogen plant. The feedback from BorsodChem MCHZ's personnel has been very positive with respect to operation of the HTCR plant: The HTCR plant is very easy to operate and requires a minimum of attendance.

Start-up and shutdown of the HTCR plant is much easier than in the existing plant according to the operators: A hot restart of the plant can be done in 2-3 hours; a procedure which typically takes 15-20 hours in the existing plant. The Load and Temperature Management system (LTM) is working very well and capacity can be increased fully automatically from 30-100 % in approx. 1 hour.

Approximately 6 months after start-up a very slow but constant deactivation of the reformer catalyst was noticed. By analysing gas samples it was detected that the natural gas used as feedstock contains organic sulphur which was not known at the time the plant was designed. In September 2006 a Co/Mo hydrodesulphurisation catalyst was installed, and a hydrogen recycle stream was established in order to eliminate the continuous sulphur poisoning. At the same time the reformer catalyst was replaced to re-establish full activity in the reformer.

A new set of operating data was collected in September 2006:

Plant Capacity	102%
Impurities in hydrogen:	
• Nitrogen	• 1.2 ppm vol.
• CO	• 2.1 ppm vol.
• CO <sub>2</sub>	• 0.0 ppm vol.
• CH <sub>4</sub>	• 0.0 ppm vol.
Natural gas consumption, feed + fuel	2,474 Nm <sup>3</sup> /h 3.46 Gcal/1,000 Nm <sup>3</sup> hydrogen
Demin. water consumption	3,991 kg/h
NOx in flue gas	75 mg/Nm <sup>3</sup>

Table 2: Operating data from September 2006

The energy efficiency for the HTCR plant is even better with the new operating data compared to the test run which can be ascribed to tuning in of the plant.

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## 10. Conclusion

Haldor Topsøe A/S has supplied a 6,000 Nm<sup>3</sup>/h HTCR hydrogen plant to BorsodChem MCHZ in the Czech Republic. The HTCR plant was engineered, constructed and commissioned in less than 18 months with start-up in June 2005. A test run was completed in 2005 with production and consumption figures meeting or exceeding the design figures. Since test run the plant has operated almost continuously at 100 % capacity and the very high energy efficiency has been confirmed with an energy consumption of natural gas around 3.5 Gcal/1,000 Nm<sup>3</sup> hydrogen.

The HTCR concept with only one burner providing the heat input for the plant has demonstrated its ease of operation with very fast start-up and shutdown procedure and adaptation to changes in hydrogen requirements. The Load and Temperature Management system (LTM) provides a fully automatic operation of the plant between 30 and 100 % load minimising operator involvement during operation. BorsodChem MCHZ's operators and plant personnel who also have operating experience from an existing conventional hydrogen plant have confirmed the superiority of the HTCR technology and expressed their full satisfaction with their HTCR hydrogen plant.