Adding Hydrogen Production Capacity by Heat Exchange Reforming

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Abstract

The demand for increased hydrogen production capacity in refineries is currently high, mainly due to an increase in refining capacity and stricter environmental fuel regulations.

Increased hydrogen production can be achieved by recovery from hydrogen rich streams, by capacity revamping of existing hydrogen units or by building a new plant. Haldor Topsøe A/S (Topsøe) has long and extensive experience in steam reforming and heat exchange reforming, both technologies being highly efficient options for hydrogen production. This paper describes revamps for capacity increase in existing hydrogen plants based on Topsøe heat exchange reforming technologies. These revamp solutions are cost efficient with short time to market and result in improved overall plant performance. For new plants, heat exchange reforming offers a possibility to build hydrogen units with high energy efficiency, little or no steam export and reduced CO_2 emissions.

1. INTRODUCTION

Refinery usage of hydrogen is currently rapidly increasing, driven by regulations requiring more stringent desulphurization and dearomatisation of fuels.

Increased hydrogen production can be achieved by recovery from hydrogen rich streams, by capacity revamping of existing hydrogen units or by building a new plant. Over the past 50 years, Topsøe has continuously focused on the development of new steam reforming technologies resulting in the design of more than 250 steam reforming units.

In the pursuit of improved energy efficiency and more flexible solutions for hydrogen production Topsøe has continued to develop and improve technologies for heat exchange reforming since 1985, when the first Heat Exchange Reformer (HER) was released. Today, more than 20 years of development and operating feedback, Topsøe has generated a unique knowledge and experience in the field of heat exchange reforming. The second generation of heat exchange reformers, the Haldor Topsøe Convective Reformer (HTCR), has been marketed by Topsøe since the early 1990's, and counts more than 25 units covering capacities in the range from a few 100 Nm^3/h up to 10,000 Nm^3/h of hydrogen[1]. The third generation of heat exchange reformers is the Haldor Topsøe Exchange Reformer (HTER) which was developed in the late 1990's, and demonstrated in full-scale from the beginning of 2003[2].

This paper describes the heat exchange reforming technologies available today and the options for adding hydrogen production capacity by heat exchange reforming, for capacity revamps as well as for new plants.

2. HEAT EXCHANGE REFORMING TECHNOLOGIES

The heat exchange reformers can be classified into two categories, viz. flue gas heated and process gas heated.

Both the HER and the HTCR reformers are flue gas heated steam reformers characterised by being very compact and by a high degree of internal heat recovery, making them highly energy efficient. The reformers are well suited both as stand-alone units and as revamp option for capacity increase of existing plants[3].

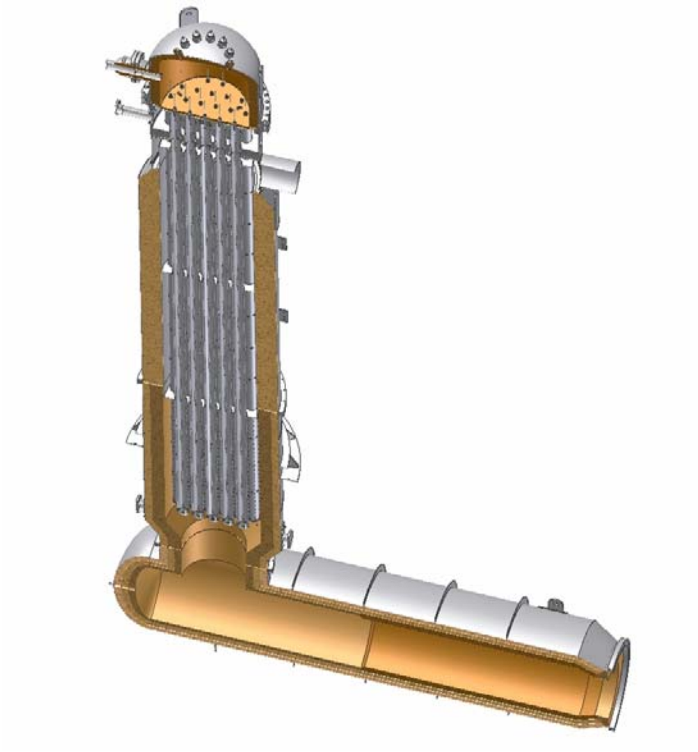

Fig. 1: HTCR concept

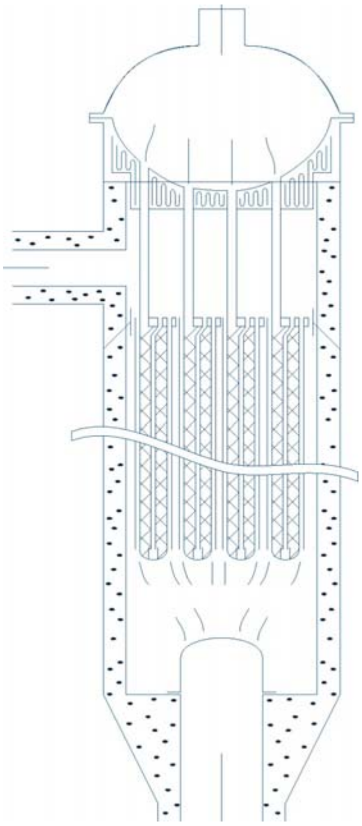

Fig. 2 : HTER concept

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

2.1 HTCR

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, see Fig. 3 below.

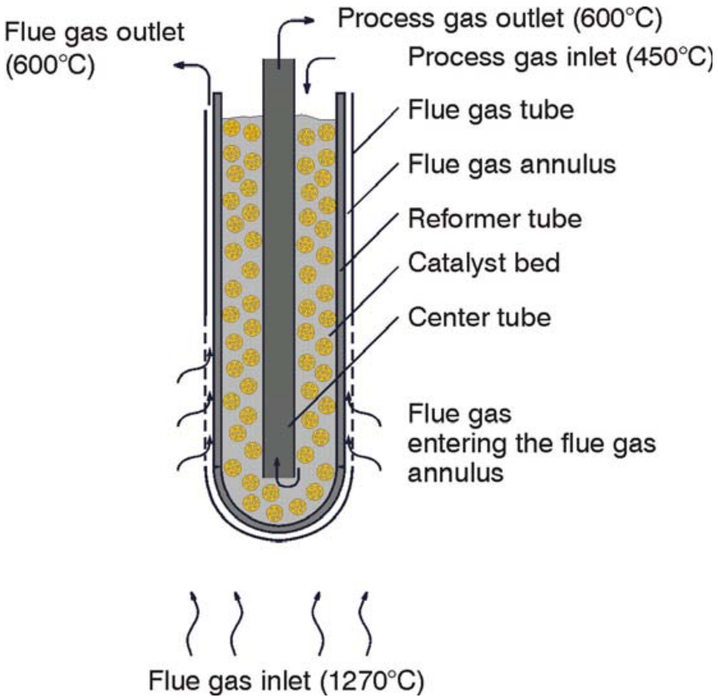

Fig. 3: HTCR tube assembly

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 an inlet temperature of 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 eliminates the risk of metal dusting while limiting the use of the 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.

2.2 HTER

The HTER can be used either as a parallel (HTER-p) concept or a series (HTER-s) concept or a combination of both[3]. The parallel and series concept of the HTER may be seen in Fig. 4.

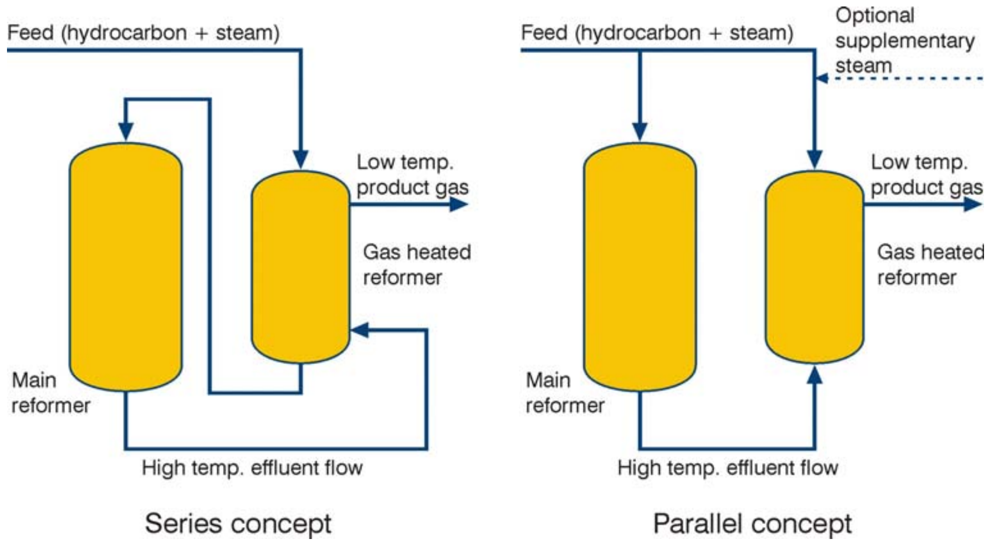

Fig. 4: Serial and parallel HTER concepts

In the series HTER 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 parallel HTER 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 series HTER 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, generally with the catalyst in the tubes and the heating medium flowing on the outside. This is frequently referred to as CATIT (CATalyst Inside Tubes). This concept is very simple and well-known from tubular steam reformers. The common and well-proven alternative is referred to as CATOT (CATalyst Outside Tubes) where the heating 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 as or even higher than the heat transfer coefficient on the catalyst side, thus resulting in optimal utilisation of the available heat transfer area. However, when 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 unfeasible.

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 Fig. 5.

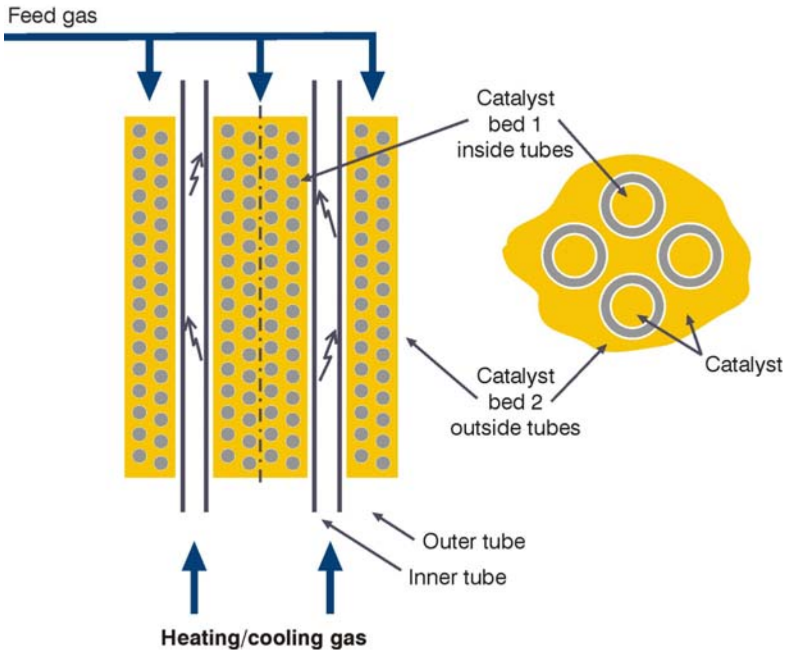

Fig. 5: The HTER double tube

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 wit the hot reformer effluent. This gas mixture then flows in counter-current through the annuli while heat exchanging with both catalyst beds. The temperatures in the HTER are strongly dependant 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 effectively have mitigated the metal dusting risk.

3. REVAMPING WITH A HTCR

As a revamp option, the HTCR is a very flexible solution. As the HTCR can be designed as a completely independent unit, the possibilities for tie-ins to the existing unit are 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 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 on-site implementation of such a solution requires a minimum of downtime as basically only three tie-ins need to be performed during a shut down. The rest of the construction can be performed during operation of the existing unit.

Regarding overall plant performance after the revamp, the specific net energy consumption figure will be decreased as the thermal efficiency of a HTCR is approximately 80% compared to a conventional reformer at approximately 50%. Fig. 6 below shows a schematic layout of a HTCR revamp solution.

Typically, a capacity increase of up to around 30% is possible with this type of revamp.

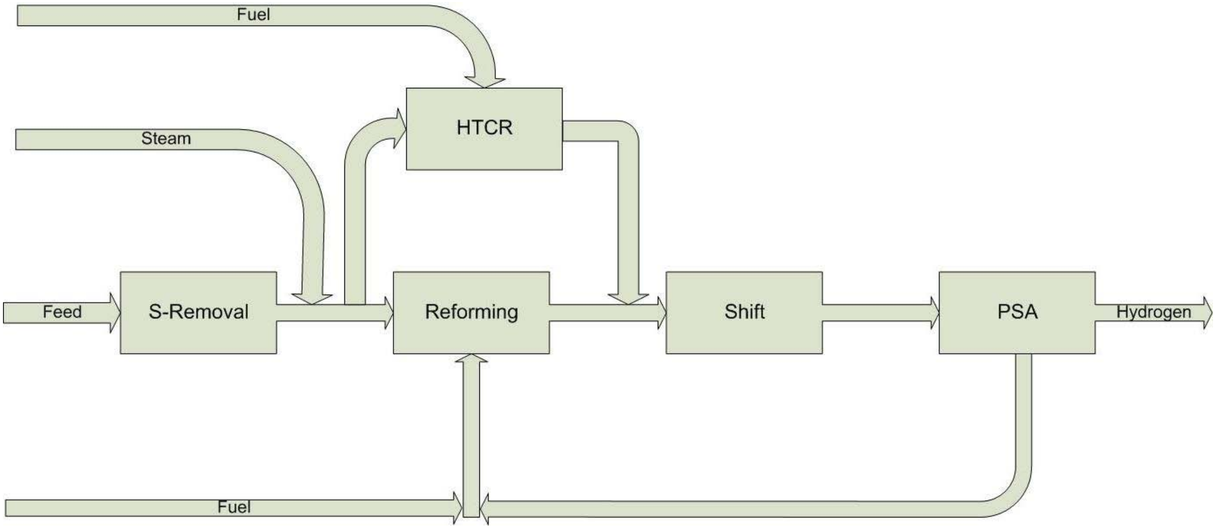

Fig. 6: Schematic layout of a HTCR revamp solution

3.1 Revamping with a HTER

Compared to 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 series HTER for revamping will inevitably lead to a significant increase in pressure drop. This may for capacity increase revamps not be acceptable. Series HTER 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 parallel HTER 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 for by adjusting the S/C ratio and the inlet temperature to the HTER. This option allows for adjustment of the operating parameters to obtain the perfect balance between size of the HTER 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 parallel HTER solution is almost as good as for the HTCR solution and more economically attractive.

A longer downtime compared to the HTCR must be accepted as the HTER is connected to the existing reformer.

The overall plant performance of the HTER revamp solution will as for the HTCR solution 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:

Table 1: Capacity increase by parallel HTER installation.

	Before revamp	After revamp	Relative change
H_2 production, Nm^3/h	49000	61250	25%
NG feed consumption, Nm^3/h	18500	22500	22 %
SMR duty, Gcal/h	41	41	0 %

A typical layout of a parallel HTER revamp solution is shown in Fig. 7.

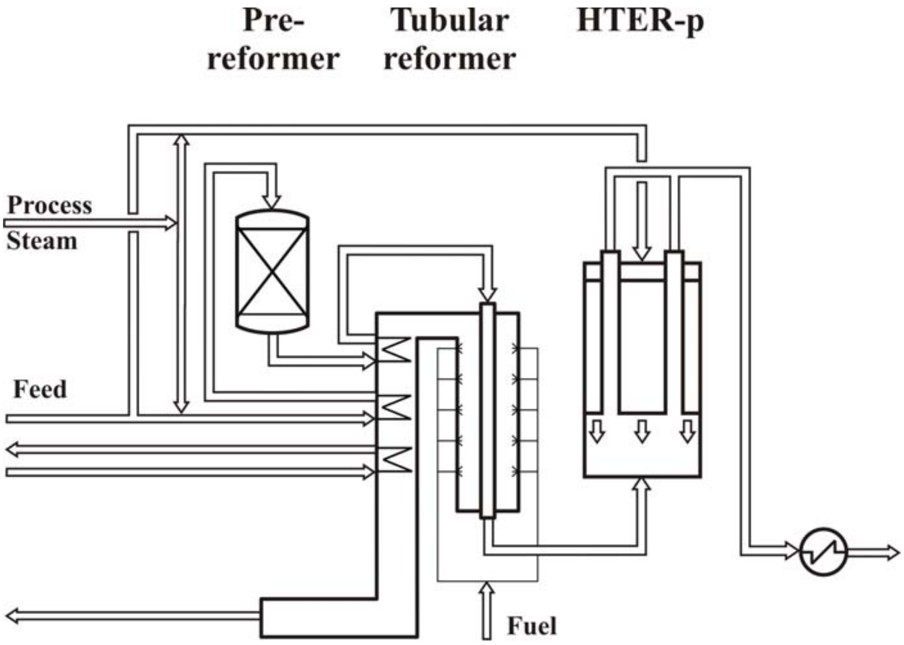

Fig. 7: Typical parallel HTER revamp layout

4. NEW PLANTS WITH INTEGRATED PARALLEL HTER

A new plant with a HTER installed in parallel with the primary reformer will have several advantages compared to a traditional hydrogen plant[4]. Integration of the highly efficient HTER gives a plant with lower fuel and power consumption, reduced steam export, increased single line capacity and lower CO_2 emissions. For a plant producing 200,000 Nm^3/h of hydrogen, the total investment cost with integrated parallel HTER is roughly the same as for a traditional plant, meaning that the layout will be feasible when favoured by the cost of feed and utilities. A typical set of data for a large hydrogen plant, with and without an integrated parallel HTER, is given in Table 2. Table 2 shows that the integrated parallel HTER layout is the most energy efficient solution of the two. Fuel consumption is reduced by 60% and steam export by 40%. Based on these figures, the layout will provide savings in cases when export steam credit is less that 70% of fuel cost on an energy basis, feed, fuel and steam cost considered. In cases where export steam has little or no value, significant savings on operating cost will be achieved. As also seen from

Table 2, the cost of electric power and/or potential CO_2 emission permits will further favour the parallel HTER layout.

Table 2, Comparison of traditional hydrogen plant and a plant with integrated parallel HTER.

Case	Traditional	Parallel HTER
Feed, Gcal/ 1,000 Nm^3 H_2	3.33	3.35
Fuel, Gcal/ 1, 000Nm^3 H_2	0.34	0.14
Steam export, Gcal/1,000 Nm^3	0.66	0.40
Power Consumption kW/1,000 Nm^3 H_2	16	14
CO2 emissions kg/ 1,000 Nm^3	900	860
Cost of feed, M USD/yr	211.42	212.68
Cost of fuel, M USD/yr	21.59	8.89
Electric power, M USD/yr	2.56	2.24
Steam credit, M USD/yr	-20.95	-12.70
Total annual operating cost, M USD/yr[1]	214.61	211.12

The parallel HTER case in Table 2 represents a design where the reforming duty is split 85/15% between the primary reformer and HTER. By shifting the duty further towards the HTER, the steam export can be further reduced and even eliminated.

5. CONCLUSION

The innovative heat exchange reforming solutions developed and industrially demonstrated by Topsøe are the optimal solutions for boosting the capacity in existing hydrogen units. The flexibility, performance, cost, implementation time, etc. are unmatched by other revamp options. The diversity of the Topsøe heat exchange reforming technologies allows for optimal utilisation of existing plant capacity in case of revamps and optimized production cost for new plants.

For new plants heat exchange reforming offers a competitive option for minimising the production cost of hydrogen and is an environmental attractive solution due to reduced emissions.

The options offered by heat exchange reforming for optimising the layout of new plants and utilising the full revamping potential of existing units is to be considered when hydrogen capacity increase is on the agenda.

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[1] Based on a NG prize of 10 USD/MBtu, a steam price of 16 USD/tonn and an electric power price of 0.1 USD/kWh