FLOX® Reformer – Hydrogen for Fuel Cells

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FLOX® Reformer – Hydrogen for Fuel Cells

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1 Introduction

Hydrogen supply and infrastructure is one of the key success factors for a broad market penetration of fuel cells. Apart from this, the limited energy density of available hydrogen storage technologies reforming of commercial fuels is required for applications which need significant operation times (hours/day) and/or power output (< 1 kW). Further on, reforming enables manufacturers to independently develop the market, thus avoiding the risk in the progress of a area-wide hydrogen infrastructure.

However, in general the fuel cell system gets more complex and costly, which puts challenging technical requirements on the reforming components. These are:

- Hydrogen generation efficiency compared or even higher than centralized production. 75-80 % is state of the art and allows electric efficiency of 30-35 % of the system.
- Cost effectiveness. In mass production determined by weight, materials and compactness.
- Minimized complexity. A simple and stable control strategy as well as a minimum number of BOP-components (valves, blowers, pumps, etc.) is desirable.
- Low noise and efficient BOP-components. Hydrogen fuel cells are a priori zero emissive and noiseless.
- Gas processing should meet the lowest emission standards and must not overcome fundamental fuel cell benefits.

2 The Product Line FLOX® Reformer compact

WS Reformer adresses these challenges and offers reformer solutions for various hydrogen capacities and fuel cell technologies in the range 1-5 kW.

Table 1: Technical Data of FLOX® reformer compact types.

Product Name	**FPM-C1**	**C1**	**C4**	**C6-HT**
	Fuel processing module 	Reformer 	Reformer 	Reformer 
Feed	Natural Gas, LPG	Natural Gas, LPG DI-water, 5 bar	Natural Gas, LPG DI-water, 5 bar	Natural Gas, LPG Wet steam, 5 bar
Hydrogen capacity	1,2-2 Nm^3/h	1,2-2 Nm^3/h	4 Nm^3/h	5 Nm^3/h
Hydrogen purity	75 % in reformate HT-PEM: CO<1 % LT-PEM: <20ppm	75 % in reformate HT-PEM: CO<1 % LT-PEM: <20 ppm	75 % in reformate HT-PEM: CO<1% LT-PEM: <20 ppm	75 % in reformate HT-PEM:CO<1%
Efficiency**	75-80 %	75-80 %	78 %	85 %
Weight	30 kg	20 kg	45 kg	45 g
Size dxh	290x360x280 mm	250 x 420 mm	350 x 700 mm	350 x 800 mm

Table 1 highlights the basic technical data. All types include FLOX® combustion technology, which allows a compact design, high heat transfer rates, low emissions and highest efficiency. The patented FLOX® reforming process comprises high pressure steam cooling of the single, integrated CO-shift stage and an internal pressure hub of the reformate in the reformer, without the use of an extra feed-gas compressor. Since the heat management separates combustion air/exhaust and product/feed heat exchange, fast load following can be realized by one single temperature control loop, which is lead simply by heat demand.

Estimations of material usage and BOP requirements reveal, that the cost targets even at mid-size series production (1000-10.000 units/a) will be met.

3 Benefits of FLOX® Combustion in Steam Reformers

Core technology is the flameless oxidation (FLOX®) burner, which allows a very compact, cost-effective design along with high combustion densities and heat transfer rates by avoiding hot spots in the combustion chamber. FLOX® reveals further benefits in anode-off gas combustion, because sophisticated stabilizing and monitoring of low calorific hydrogen gas flames is inherently avoided. Further on, FLOX® makes extreme air-preheating at ultra low NOx emissions possible. This is of greatest significance for the design of highly efficient HT-PEM systems.

4 Efficient High-Temperature PEM Systems

Latest developments and progress in durability [1] make HT-PEM fuel cells a serious commercialisation candidate for small, low-noise power-generators as well as for CHP-applications.

Considering the whole reformate fuel cell system, the advantages of HT-PEM compared to LT-PEM systems are obvious: cathode air humidification and CO-fine cleaning (<10 ppm) can be removed and the operation temperature of some 160 °C promise a more “valuable” heat level for heating purposes. Main disadvantages or problems occur by the reduced current density and cooling issues, particularly at larger stacks. The latter gets particularly important at CHP applications. Air cooling is no option, but cooling by generation of process steam in the stack as described in [2,3] is an elegant and advantageous solution. How this can be technologically realized at low cost shall not be discussed here. However, the implications for the reformer system will be emphasized and solutions will be presented.

Firstly, external steam generation (heat of vaporization, Δdhv=0,556 kWh/l) increases the reformer efficiency. It has been shown [4] that the increase lies in the range of 5 % and therefore has got the potential to compensate the efficiency drawback of the HT-PEM fuel cell. That means, also HT-PEM Systems can be operated at an overall electric efficiency over 35 %.

However, this has got significant impact on the reformer design, it’s internal heat management and combustion technology. In the following we summarize the findings of an extended pitch-point analysis of the reforming process based on reforming of 1 Nm^3/h natural gas (10 kW) at 750 °C and S/C=3. Product gas has got a temperature of 200 °C (CO-Shift level) and the exhaust gas of the burner is assumed to be 250 °C. Fig. 1 shows the relevant heat fluxes and streams. The feed (natural gas/water) has to be heated up from 20 °C to 750 °C, the product gas has then to be cooled down to CO-Shift inlet (200 °C). Biggest heat sinks are reforming (1) and vaporization of water (4). The CO-Shift reaction releases heat (6). On the combustion side one has to account for preheating air and fuel (8) up to combustion temperature and subsequently cooling down the exhaust gas (7). For completion, wall heat and gas flow losses (3) are also shown. The overall energy balance is then closed by the fuel demand (not shown).

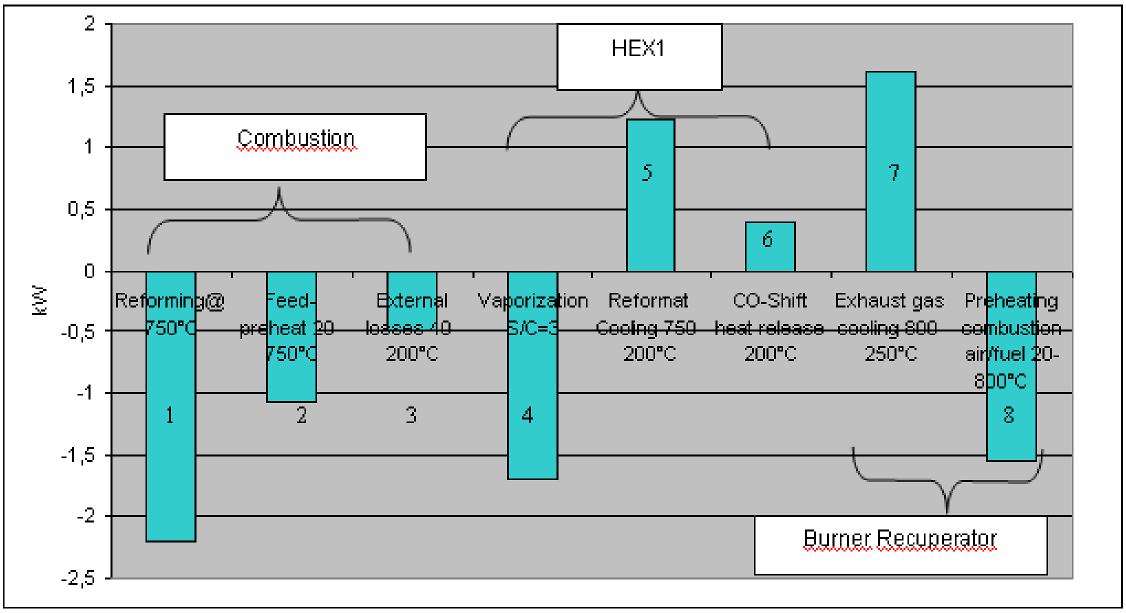

Figure 1: Heat flux and balancing in FLOX® reformers at 1 Nm³/h natural gas feed (methane).

In the productline FLOX® reformers compact C1 and C4 vaporization (4) balances reformat cooling (5) and CO-heat release (6) (HEX1). The combustion air and fuel (anode-off gas + NG fuel) is preheated (8) in the recuperator of the FLOX® burner by cooling down the exhaust gas (7). Preheating of feed (2) and reforming (1) takes place in the actual reforming reactor and is supplied by combusting the fuel. The advantages of this process are described in detail in [4].

Competitive concepts usually use exhaust gas heat (7) for vaporization (4). Feed preheating (2) can then be realized by reformate cooling (5). External air/fuel preheating is not necessary and takes place in the actual combustion chamber. The overall balance and efficiency of both concepts is equal as long as the temperatures of product- and exhaust gas as well as wall losses are identical.

However, considering the high efficient HT-PEM system, the heat sink "vaporization" is omitted within the reformer. That means, in order to balance the system the only remaining "heat sink" air/fuel preheating (8) is mandatory. This has tremendous influence on the combustion technology, because in classical flames external air preheating (600-700 K) leads to exponentially increased NOx emissions. For this reason, the author does not see an alternative to FLOX® combustion for high-end HT-PEM systems.

5 Efficient Solutions in the 5-kW class: FLOX® reformer compact C4/C6-HT

According to the requirements of the application, WS Reformer offers two solutions in the 5 kW class.

The C4 has got an internal steam generator and has to be fed with demineralized water, which usually is recycled in a condenser from the cathode air and the exhaust gas. The only additional BOP components are a water pump (e.g. membrane type, p=5 bar) and the air blower for the burner (60 mbar). Gas processing sub-system and fuel cell sub-system are fairly decoupled. Once the combustion air (60 mbar) is supplied by the cathode air blower of the stack, the integration can be increased. The overall electric efficiency of the system then lies for LT-PEM system between 30 and 35 %, combined with HT-PEM stacks at state-of-the-art, 27-30 % seems to be achievable [5].

With the C6-HT, the integration between gas-processing and fuel cell is enhanced. The reformer needs wet steam as feed input, which preferably is generated by the stack heat directly in the HT-PEM fuel cell or in a secondary cooling circuit. The FLOX® burner including the air/exhaust gas recuperator and the reformer reactor remain the same as in the C4. In contrast to the C4, feed preheating (2) balances reformate cooling (5). The achievable overall electric efficiency for the concept is between 35 and 40 %. Although there are some challenges and restrictions with regard to tolerances in steam quality, the concept promises further simplification of the process, leading to dramatic cost savings and stable operation without sophisticated control strategies.

References

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