WHEC 2012 19th WORLD HYDROGEN ENERGY CONFERENCE 2012
Toronto, Canada | June 3rd–7th

Boundary Conditions and assumptions Influencing the Power Needed to Liquefy Hydrogen

Abstract

The goal of the IDEALHY project is to identify processes and components which allow to liquefy hydrogen with much lower power consumption than LH_2 plants built to date. Although the design of the liquefaction process is central to this investigations, the total power consumption depends on a number of key boundary conditions and component efficiencies. Statements on the overall power consumption for the liquefaction process are not exact without specifying values for these boundary conditions.

The most important boundary conditions to be considered are: Pressure, temperature and purity of the hydrogen feed; temperature and available flow rate of the ambient temperature heat sink; desired storage pressure and para-hydrogen content of the produced liquid hydrogen; heat leak to the storage tank(s) and the liquid transfer system.

For the comparison of different hydrogen liquefaction cycles, a set of boundary conditions and component efficiencies has been selected. These have been applied for two basic processes, were the hydrogen is cooled and liquefied either at 20 or at 80 bar. The minimum exergy losses caused by heat transfer and non-ideal expansion have been calculated. The result is, that with the chosen boundary conditions and component efficiencies the minimum power requirement in both cases is about 4 kWh/kg.

So far no real refrigeration processes have been considered: The refrigerant, the number and position of the expansion turbines have not yet been chosen, power recovery of expansion turbines has not been investigated and pressure drop has so far been neglected. All these factors will probably cause additional exergy losses and thus additional input power to the compression. With the presented result a lower bound, which is possible with the chosen boundary conditions and efficiencies has been established.

Boundary conditions (see Table 1)

Purity:

- It is expected, that the feed hydrogen will contain some impurities in the 100 ppm range.
- These impurities will be removed by adsorption at the 80 K level. Extra power consumption is estimated to be negligible.

Pressures of feed and product:

- Choices have quite a large influence on the power consumption. Sensitivity analysis will be performed

Assumed component efficiencies

- Table 2 shows the assumed efficiency related assumptions implemented in the figures given in Table 4
- Table 3 present the efficiency figures to be used for further cycle comparisons, including the real refrigeration plants for precooling and cryogenic temperatures, not included here.
- In later stages, efficiencies defined in dialogue with manufacturers will be implemented.

Exergy and power balance

- The exergy requirements for the liquefaction are about the same independent of whether the pressure during hydrogen cooling and liquefaction is 20 or 80 bara with the current assumptions, as shown in Table 4.
- In the 20 bar process the cooling of the hydrogen, the heat transfer and the expansion require more power. Whereas in the 80 bar process, the compression of the feed from 20 to 80 bar requires additional power. The overall power consumption is about 4 kWh/kg in both cases.
- It should be pointed out, that this is the absolute minimum for the chosen boundary conditions and component efficiencies. It is based on the assumption that the refrigeration is produced by expansion exactly at the same temperature where it is needed for the cooling of the feed.
- If one inspects the specific heat vs. temperature, see Figure 1, one observes a sharp peak at 35K for hydrogen at 20 bar. Running the refrigeration cycle at 80 bar shifts the cooling re quirements to higher temperatures. This, in theory, increases the cycle efficiency but needs, in praxis, to be matched to feasible components such as expanders and heat exchangers.

Table 1

Feed	Pressure	20 bar
	Temperature	293 K
	para-content	25 %
	Purity	pure hydrogen
Product	Pressure	2 bar
	Temperature	22,8 K (saturated)
	para-content	98 %
	Purity	pure hydrogen
Cooling water	Temperature	293 K
	Temperature rise	10 K
Heat leak	Process	none
	Storage	none

Table 2

Heat exchange	Cooling water pinch point temperature difference	5 K
	i.e. outlet temperature from inter- and after-coolers of compressors	298 K
	Condensing temperature of refrigerants like propane	303 K
	Sub-cooling of condensate to	298 K
	Whole cryogenic train	NTU < 120
	Pinch point at warm end	3 K
	Pinch point at 80 K level	1 K
	Pinch point at cold end	0,3 K
Pressure drop	Inter- and after-cooler H2	0,2 bar

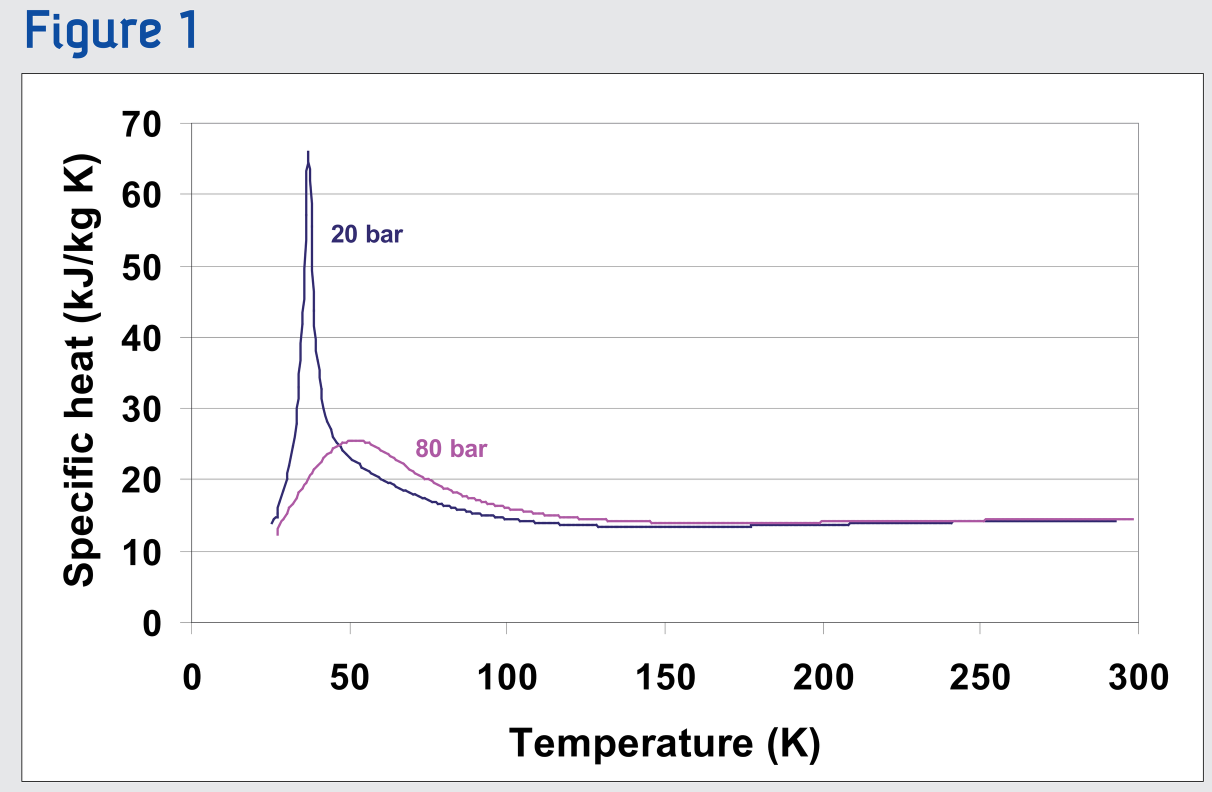
Table 3

Pressure drop	Above 20 bar	2 %
Cryogenic part	medium pressure: 4 bar	5 %
	low pressure	20 %
Compressor, isentropic efficiency	Piston and turbo-compressor	85 % per stage
	Turbine brake compressor	80 %
	Cold compressor	70 %
Expander, isentropic efficiency	Expansion turbines below 120 kJ/kg enthalpy drop	
	Wet expander	85 %
Ortho-para conversion	Temperature delay	2 K

Table 4

Pressure during H_2 liquefaction	20	80	bara
Cooling of feed	8624,3	7096,2	kJ/kg
Heat exchange losses	263,1	227,6	kJ/kg
Expansion losses	1319,3	1165,5	kJ/kg
Total cooling, hx and exp	10206,7	8489,3	kJ/kg
Eff. compression refrigerant	0,7	0,7	-
Compression losses refrigerant	4374,3	3638,3	kJ/kg
Eff. hydrogen compression		0,75	-
Exergy 20 - 80 bar compression		1717,7	kJ/kg
Compression losses H_2		572,6	kJ/kg
Total consumption	14581	14418	kJ/kg
Required power consumption	4,05	4	kWh/kgH_2

Figure 1



Kawasaki
PLANET GbR
WEKA
NORTH ENERGY
TECHNISCHE UNIVERSITÄT DRESDEN
Loughborough University
Linde
New Energy World JU
fuel cells & hydrogen for sustainability
idealhy
Integrated Design for Efficient Advanced Liquefaction of Hydrogen
SINTEF

The research leading to these results has received funding from the European Union's Seventh Framework Program (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement n° [278177]

Authors:

H. Quack, J. Essler and Ch. Haberstroh
TU Dresden

P. Nekså, D. Berstad, M. Drescher, J. Stang and H.T. Walnum
SINTEF Energy Research

L. Decker, Ph. Treite
Linde Kryotechnik AG

Contact:
Hans.Quack@TU-Dresden.de