Introduction to Small Size Hydrogen Liquefier

Urs Fitzi

Linde Kryotechnik AG, Dättlikonerstrasse 5, CH-8422 Pfungen, Switzerland

Small size hydrogen liquefiers are easy to operate and are mainly built to serve as a test facility to produce liquid hydrogen on demand. Liquefied hydrogen is used in the aerospace- and electronic industry and in the future maybe as a fuel for public transportation. In economical flourishing countries there is an increasing demand for hydrogen at rocket test sites, whereas in the high tech industry ultra pure hydrogen is needed. An overview of a small hydrogen liquefier will be presented with its key component compressor, cold box, turbo expanders, heat exchanger, ortho-para (op) catalyst, and storage tanks.

INTRODUCTION

All hydrogen liquefier regardless of the cycle chosen consist of the key components compressor system, cold box that includes turbo expanders and heat exchanger partially filled with op catalyst, and the liquid storage tank. The cold box itself consist of the nitrogen and recycle loop that contribute refrigeration to the feed loop where the temperature of the hydrogen gas is continuously lowered by the heat exchangers and the conversion of para- to ortho-hydrogen takes place. There are numerous publications and books [1,2] on the different liquefaction cycles and the aim of this paper is to focus on some specific key factors that make up small state of the art hydrogen liquefiers.

RECYCLE COMPRESSOR SYSTEM

Within the recycle compressor the gas is pressurized to approximately 2.0 MPa and at a later stage expanded for utilizing refrigeration. Currently, screw or piston compressors are used depending on the size of the liquefier. For small liquefiers screw compressor are used since there cost/efficiency ratio is better compared to piston compressors.

With a screw compressor that conveys helium, and in the future hydrogen, gas bearing turbines are implement in the process. A disadvantage for the screw compressor is the necessity of oil as a lubricant, which has to be separated from the carrier gas before it enters the cold box. Piston compressors are used for liquefiers with a production capacity larger than 1000 litres per hour. Efficiency of a piston compressor can be as high as 70 percent whereas for the screw compressor it is 50 percent. Piston compressor have the disadvantage that they are expensive in acquisition and maintenance compare to screw compressors.

For large hydrogen liquefiers up to 180'000 liter per hour a combination of centrifugal and reciprocating compressor would be used. World Energy Network (WE-NET) has estimated that with a combination of the different compressor systems an efficiency of more than 80 percent can be obtained. More research and actual data is needed to decide on the most efficient set up [3].

COLD BOX AND ITS COMPONENTS

Within the cold box the hydrogen will be cooled from approximately 300 to 80 Kelvin by a nitrogen cycle. From 80 to 30 Kelvin refrigeration is provided by the turbo expanders included in the recycle loop and at the same time the temperature of the hydrogen within the feed is continuously lowered by simultaneous conversion of para- to ortho-hydrogen [2].

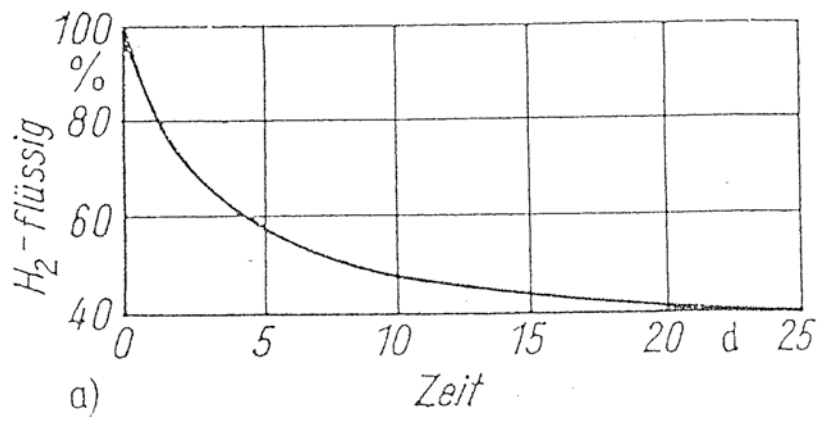

Figure 1 Evaporation of Normal Hydrogen [4]

In comparison, if the hydrogen is liquefied without continues conversion, 5.1 MJ/kg more energy is required. In addition, if ortho-hydrogen would not be converted to para during liquefaction more than 60 percent would evaporate during a time period of 25 days as shown in Figure 1.

From 30 Kelvin to liquid hydrogen a so called Joule-Thomsen valve is used. The more imperfect the gas the better is the J-T effect as a comparison of isenthalpic and isentropic expansion coefficient demonstrates:

$$\mu_H - \mu_S = -\frac{V}{C_P} \qquad (1)$$

with μ_H: isenthalpic, or Joule-Thomson, expansion coefficient, μ_S: isentropic expansion coefficient, V: Volume, C_P: specific heat. When C_P tends to infinite or V approaches zero the J-T effect is favoured. Therefore, preferred conditions of the J-T expansion are low temperatures and high pressure as shown in Figure 2 [1].

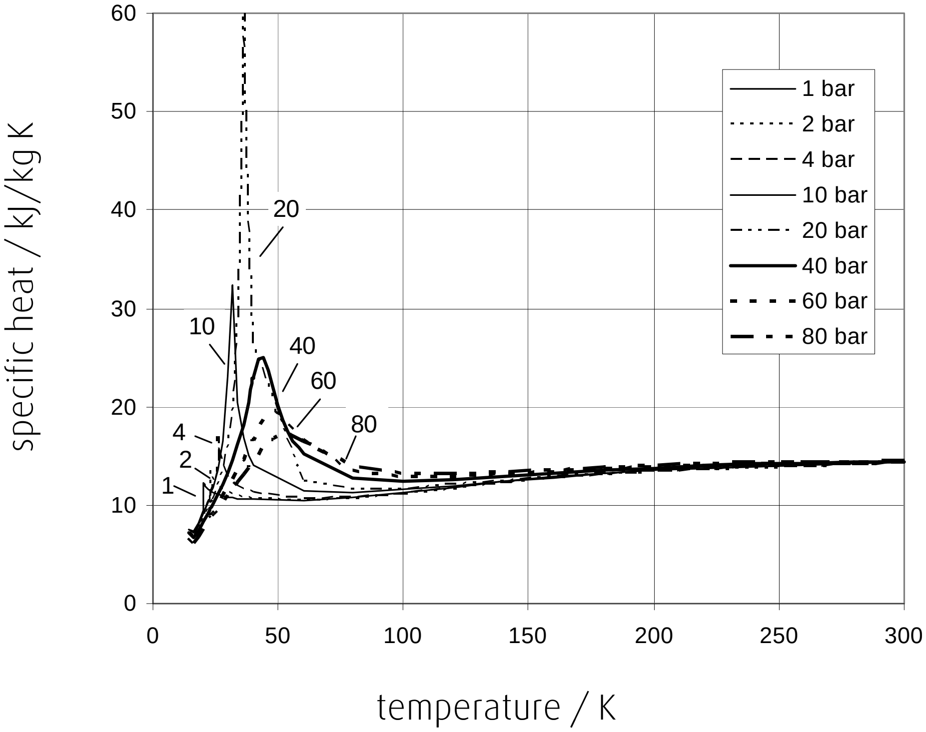

Figure 2 Specific Heat of Hydrogen versus Temperature

Several institutions have carried out different studies to investigate the efficiency increase of large hydrogen liquefiers. Figure 3 summarizes theoretical and field data for different energy requirements versus hydrogen liquefaction capacities. It shows, that with increasing liquefaction capacity the energy requirement is decreasing.

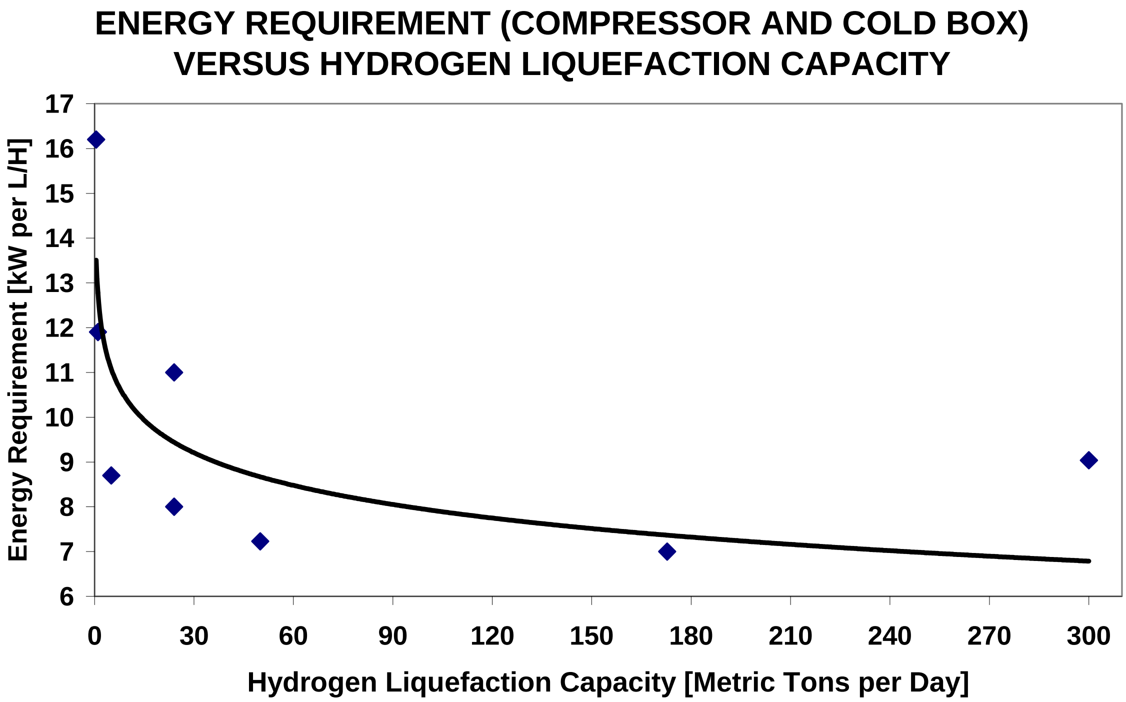

Figure 3 Hydrogen Liquefaction Capacity for Variable Plant Sizes

For small hydrogen liquefiers there is a sharp decrease of energy requirement if the liquefaction capacity is increased, whereas for larger plants there is no significant difference. In order to reduce the energy requirements one cannot just increase the plant size or hydrogen liquefaction capacity. Instead, single components of the hydrogen liquefier have to be developed to be more efficient [3,5,6,7].

STORAGE TANK

There are various size of liquid hydrogen storage tanks of up to 3800 nominal cubic meter (m^3). Main consideration for storage tanks is to keep the evaporation of hydrogen to a minimum. The largest tank are spherical in shape since the ratio of surface area and volume is minimal compared to other configurations, nevertheless are cylindrical tanks built as well since acquisition cost are lower. Evaporation rates range from 0.3 for small to 0.04 percent per day for the largest liquid hydrogen storage tanks [8].

Storage tanks include sophisticated thermal insulation systems to reduce conductive, convective, and radiant heat flow into the liquid hydrogen to minimise evaporation. These materials include: perlite, silica aerogel, multiple layers such as Mylar or other low conductive materials. The space between the two shells is under vacuum to minimise the evaporation rate further [8].

FUTURE OUTLOOK

Even though there have been numerous sizes of hydrogen liquefiers been built there is still room for improvement. Research and technology development should be carried out in support of novel concepts that promise major improvements in the cost and efficiency of compressor systems, cold box including op catalyst and turbo expanders, and distribution systems. Several institutions have developed cost modules for producing, handling, distributing, and dispensing hydrogen from a central plant and fuelling station on-site facility for fuel cell vehicle applications. Depending on the source and input data the cost for hydrogen varies between $4 up to $12 per kilogram of hydrogen. It is predicted that this cost could be lowered to $1 which would be competitive with gasoline prices [5,6,9].

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