TECHNICAL NOTE

"INSIDE-OUT" vs. "OUTSIDE-IN" HYDROGEN PERMEATION FROM A HIGH CRUDE STREAM.

Hydrogen purifiers based on permeation through palladium alloys fall into three general classifications:

A. Tubing type purifiers configured so that the feed gas is contained in the bore of the tubing and the product gas is withdrawn from the outside surface of the tubing. ("Inside-out.")

B. Tubing type purifiers in which the feed is presented to the outer surface of the tubing and the product is withdrawn from the bore. ("Outside-in.")

C. Sheet or foil type units.

Purifiers of type C are not available in the United States and this analysis is limited to types A and B.

All permeation-type purifiers require a sweep or bleed gas to prevent the accumulation of impurities at the upstream permeation surface. "Inside-out" purifiers provide this sweep by the insertion of a dip-tube catheter into relatively short closed-one-end tubes or by connecting both ends of relatively long tubes to appropriate feed and bleed lines. In both cases, the path of the feed stream is closely constrained and all gas which escapes as bleed is exposed to the full interior surface of the permeation tube before it is vented. "Outside-in" permeation systems are generally made of multiple parallel straight lengths of closed-one-end tubing sealed at their open ends into a block which also acts as a barrier between the feed and product gas volumes. The path of a feed gas across or along such a bundle is not strongly constrained and a portion of the crude gas passes directly from feed inlet to bleed outlet. In addition, where the feed contains appreciable impurities, the most effectively shielded areas of the tube bundle are enriched in impurities and depleted in hydrogen in such a manner as to lose a large fraction of their driving force for permeation.

The quantitive behavior of inside-out units in the presence of highly crude streams can be predicted quite accurately from a plot of the type shown in Figure 1. Figure 1 shows (schematically) the hydrogen partial pressure both inside and outside of a permeation tube as a function of distance along the tube. The driving force for permeation and thus the throughput is controlled by the area between the upstream (crude gas) and downstream (product gas) partial pressure curves. Three upstream partial

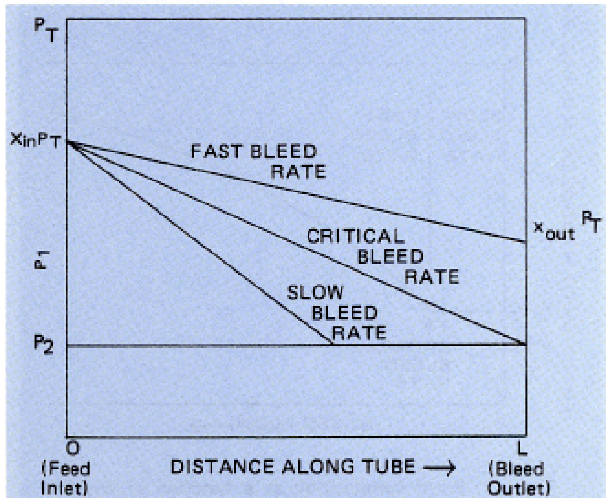

Figure 1 Upstream hydrogen partial pressure (P_1) along the bore of a permeation tube as a function of bleed rate. P_T= total feed gas pressure. x_{in}= fraction of hydrogen in feed. x_{out}= fraction of hydrogen in bleed. P_2= product hydrogen pressure

pressure curves are shown, one generated by a slow bleed rate, one by a "critical" or "optimum" bleed rate and one by a fast bleed rate. Figures 2 and 3 show the consequences of this plot in the interrelationships between bleed flow, bleed composition and product flow. The plot in Figure 1 could be modified to include the effects of pressure drop or preheater inadequacy at high flows if necessary, but such refinements are beyond the scope of this note.

Empirical observations have confirmed the following characteristics predicted by Figure 1 for well swept inside-out purifiers:

1. At slow bleed rates, the partial pressure of hydrogen in the bleed is a constant and is equal to the product hydrogen pressure.
2. Slow bleed rates are characterized by maximum recovery of hydrogen from the crude stream. (Hydrogen thrown away in the bleed is at an irreducible minimum.)
3. Fast bleed rates increase product flow at the expense of recovery efficiency.

Figure 3 summarizes the results of a series of experiments with a simulated cracked ammonia feed with inside-out and outside-in purifiers of comparable capacity when operated from a commercially pure feed at the same feed and product pressures. It was not possible with the outside-in purifier either to reduce the

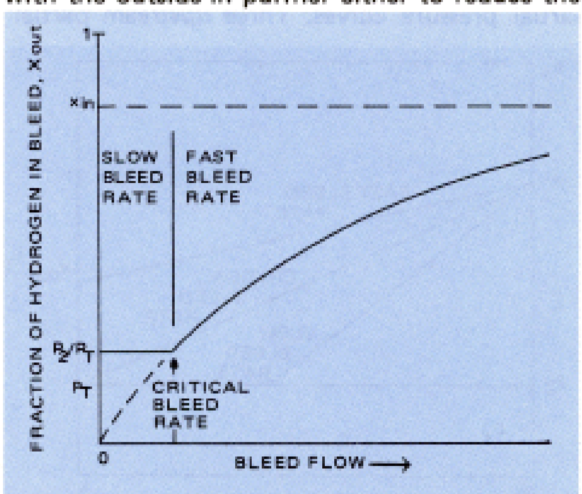

Figure 2 Bleed composition as a function of bleed rate for an "inside-out" configuration purifier. (Schematic.)

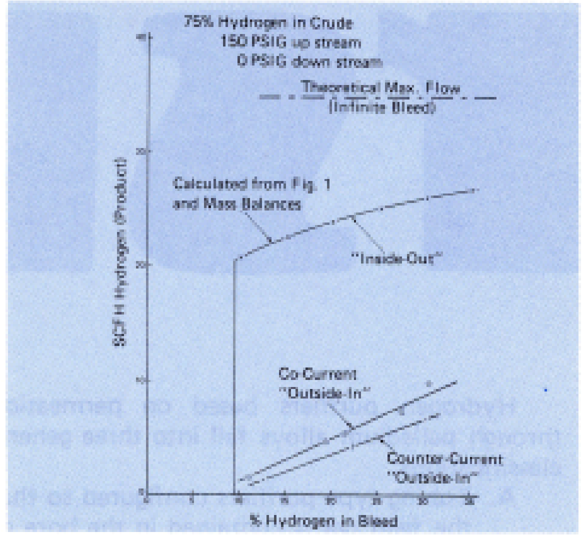

Figure 3 Hydrogen throughput as a function of configuration and bleed composition

hydrogen in the bleed to the theoretical minimum value (by decreasing the bleed rate) or to approximate the product flow obtainable from the inside-out purifier. Presentation of the feed gas co-current to the flow of pure gases in the bores of the tubing bundle proved to be preferable to countercurrent flow over the experimental range.

These experiments have aided in the rational design of inside-out purification systems for use with highly crude streams. For each unit, there proves to be one bleed rate at which the product flow is a maximum for maximum recovery of hydrogen. Slower bleed rates do not utilize the full permeation capabilities of the system and faster bleed rates reduce recovery efficiency. Engineering decisions on unit size have been made on the basis of optimization of factors including current and projected feed gas costs and the value of the hydrogen lost in the bleed, as well as the normal trade-offs in capital investment, size, operating expense and the like.

RESOURCE SYSTEMS manufactures a full line of palladium-alloy hydrogen purifiers utilizing the "inside-out" configuration. Standard purifiers are available with capacities from 1 to 500 SCFH. RSI is prepared to quote on standard or special purifiers for operation from highly crude feed streams.

resource systems, inc.

SEVEN MERRY LANE · EAST HANOVER, NJ 07936
Tel.: 973-379-3662 · Fax: 973-515-3166
E-mail: sales@rsipurifiers.com

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