Fauske & Associates, Inc.

Date: September 24, 2003

To: Jim Shelor, Jim Sloughter, Darrel Duncan, Hanford SNFP

From: Martin G. Plys, FAI

Subject: **Flammability and Combustion of H2, Air or O2, and Ar Gas Mixtures**

Flammability and combustion characteristics for hydrogen, air or oxygen, and argon are discussed here to assist evaluation for the KE sludge removal process with an argon gas purge.

For the case where a large diameter container (LDC) is purged by Ar, but H_2 and O_2 may evolve, flammability data given by Coward and Jones are available for the case of the ratio of O_2/Ar equal to the ratio of $O_2/(N_2+Ar)$ in air, which is 0.21/0.79. The lean flammability limit is 3.2% H_2, 76.5% Ar, and 20.3% O_2. This is slightly lower than the value of 4% hydrogen in air. The rich flammability limit is 76.4% H_2, 18.6% Ar, and 5% O_2 which is exactly the same oxygen content for the case of hydrogen in air. For practical purposes the rich limit of 5% O_2 is the value of interest to the project and is recommened except as follows.

A reference cited by Coward and Jones, Van Heiningen 1936, provides flammability data for the case of H_2-Air-Ar mixtures, which may be pertinent to the case of an LDC containing only hydrogen and argon but with in-leakage of air or incomplete purging of air. These data are reproduced in Figures 1, 2, and 3, which provide the overall flammability limit, a closeup of the lean limit, and the equivalent oxygen at the rich limit, respectively. Both lean and rich limit data for low Ar concentrations lie between today's known upward and downward propagation limits, and are an artifact of the experiment size and ignition location. Thus the fuel concentration decreases toward 4% on the lean limit as Ar is added, and the oxygen concentration also decreases. However, the oxygen concentration goes below 5% near 50% Ar, an unexpected result, and is about 4.1% at 70% Ar. This cannot be explained by the apparatus alone and cannot be discounted for industrial application. Thus, for the case of air ingression into an existing H_2-Ar mixture, a lower oxygen limit between 4% and 5% is recommended by using a linear fit: $x_{O2} = 5 - (x_{Ar}-50)/20$ where x is mole percent and $50\% < x_{Ar} < 70\%$. Use 5% O_2 when $x_{Ar} < 50\%$ and use 4% O_2 when $x_{Ar} > 70\%$. However, the mixture is completely inert when $x_{Ar} > 76\%$.

16W070 West 83rd Street | Burr Ridge, Illinois 60527 | E-Mail: plys@fauske.com
Phone: (630) 323-8750 | Telefax: (630) 986-5481

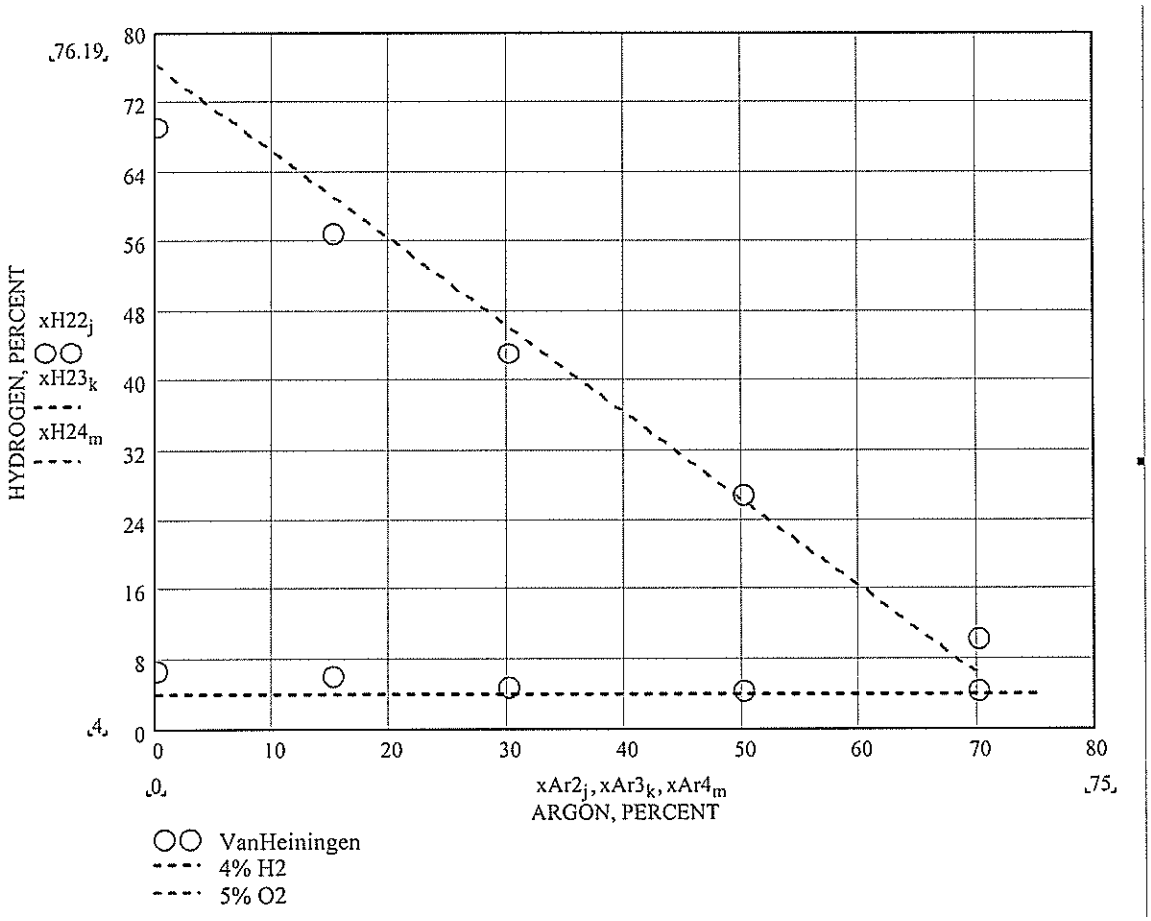
Lastly, it should be noted that because Ar has a lower heat capacity than air, the post-combustion pressure of a flammable mixture is higher with Ar than with air. Figure 4 provides the post-combustion pressure for a set of mixtures with various O_2 concentrations as indicated, beginning with a minimum stoichiometric quantity of hydrogen, so that rich mixture results are shown. Complete combustion is assumed in the absence of data near the rich limit.

References:

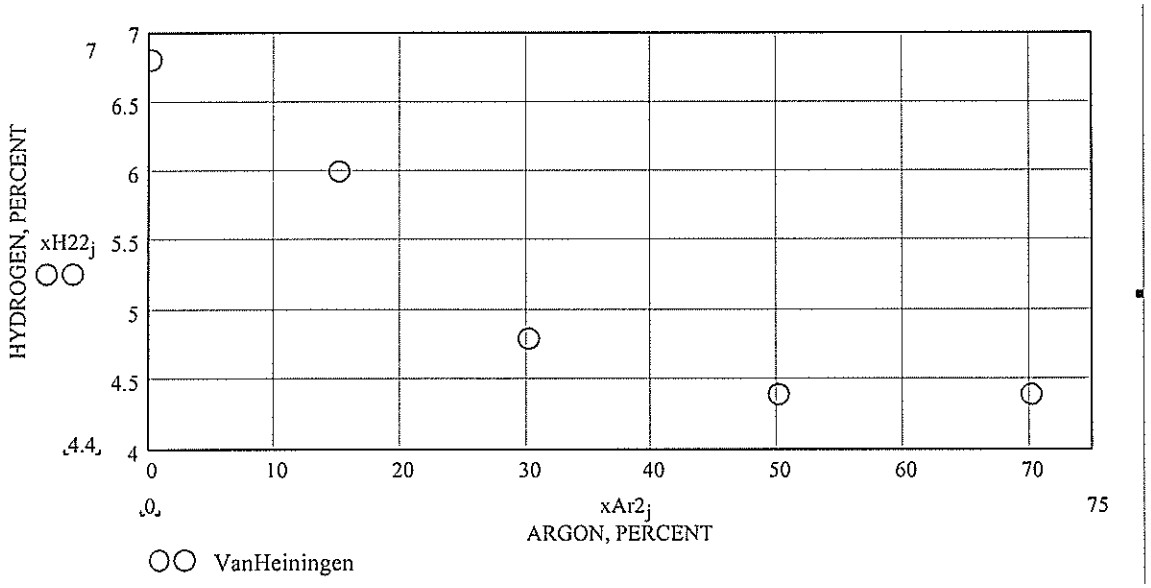
H.F. Coward and G.W. Jones, Limits of Flammability of Gases and Vapors, U.S. Bureau of Mines Bulletin 503, 1952.

J. Van Heiningen, Explosion Limits I: On the Influence of Argon, Nitrogen, Helium, and Carbon Dioxide on the Explosion Limits of Hydrogen, Carbon Monoxide, Methane, and Butane in Air, Receuil des Travaux Chimiques des Pays Bas, Vol. 55, pp. 65-75, 1936.

Figure 1. Flammability Limit Data for H_2-Air-Ar mixtures, Van Heiningen, 1936. For reference lines of 4% H_2 and 5% O_2 are drawn.



Figures 2 and 3. Closeup of Figure 1 lean flammability limit (top) and oxygen percentage at the rich flammability limit (bottom).



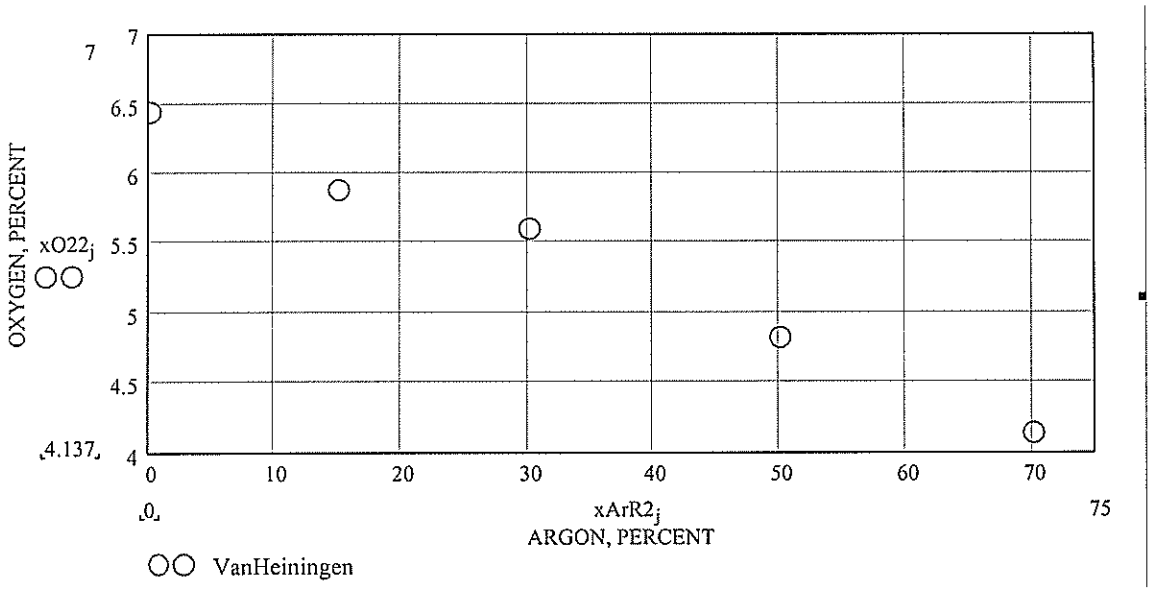
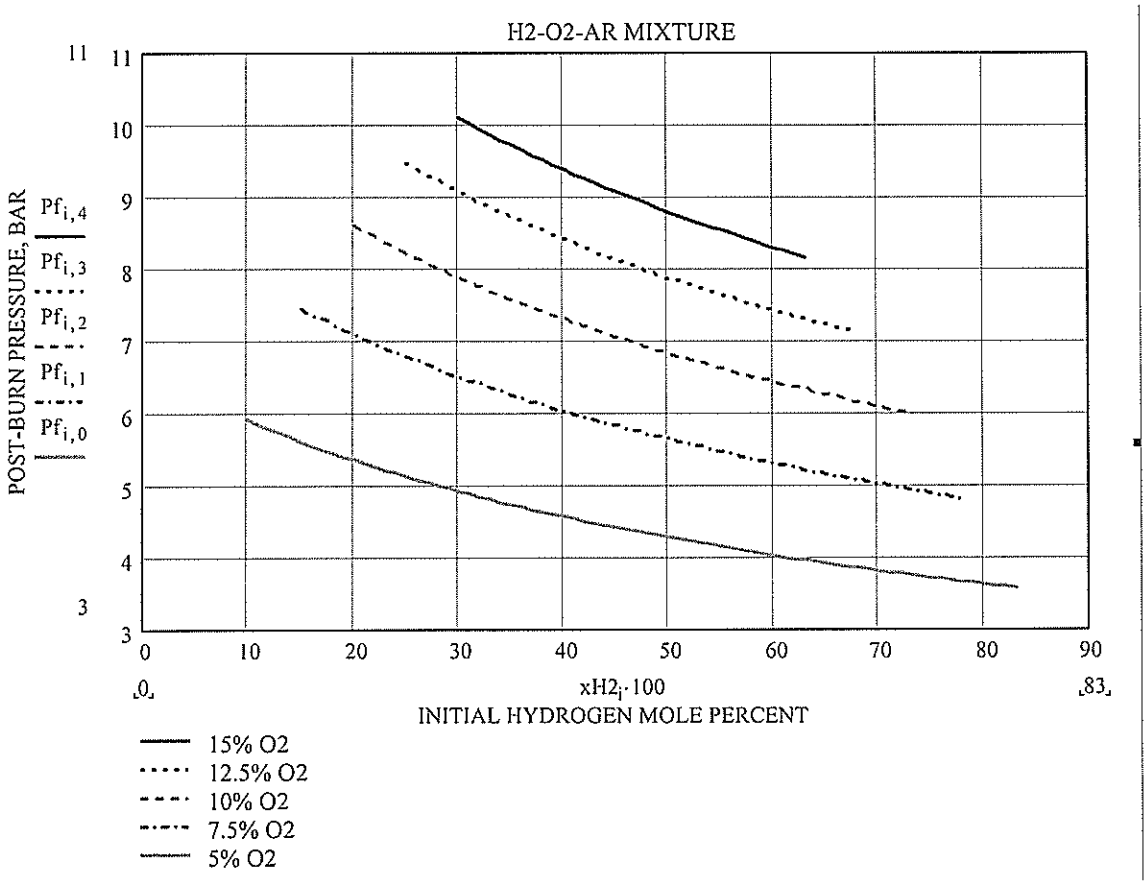


Figure 4. Post-combustion pressure for H_2-O_2-Ar mixtures with various O2 proportions and a minimum H2 stoichiometric content.



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