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White Paper

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SUBJECT: **Vacuum Life – Oil Tech Services, Vacuum Insulated Tubing (VIT)**

The life expectance of Vacuum Insulated Tubing is based on the installed Getter materials becoming fully (100%) sorbed. Getter is fully sorbed when it is without capacity or ability to sorb (pump) additional gas molecules. The quantity of Getter installed into VIT joints is based on laboratory testing and analysis and field trials. Based on this work, and the presentation below, a sufficient quantity of Getter material is installed into VIT joints to provide for a 20-year vacuum life. After the Getter is fully sorbed, the annulus will generally become Hydrogen gas filled at partial pressure based on the environment where it is installed. The VIT joint remains serviceable, only the conductivity value and insulating performance is lower and based on K-Value (thermal performance) for Hydrogen gas backfill and the multiple layers of radiation barriers, ceramic insulating paper, and fiberglass cloth installed into the original product.

Vacuum type insulation systems are highly effective, but several items must be addressed if an adequate vacuum life is to be assured. These are:

- Desorption of gases from the inner and outer tube,
- Desorption of gases from insulating materials,
- Cracking, fissuring or porosity to the welds or tube materials; and
- Diffusion of hydrogen gas through the tube walls into the vacuum.

The first three (3) items are controlled by the Oil Tech Services manufacture processes and materials selections. These processes are covered in other presentations by Oil Tech Services. We remain confident our manufacturing processes including welding, bake-out, gross quantity of Getter installed into the annulus, and raw materials selection confirm a 20-years vacuum life. The last item, diffusion of hydrogen gas through the tube walls into the vacuum is covered herein.

Hydrogen is the smallest of all atoms. Its small size allows rapid interstitial diffusion through most metals. Hydrogen moves in-and-around around the atomic matrix structure of the steel inner and outer tubes and no exchange in lattice positions need occur. Oil Country Tubular and mild steel have a Body Centered Cubic matrix structure making them more open compared to Aluminum, Lead, etc. The Body Centered Cubic matrix structure makes them susceptible to gas diffusion.

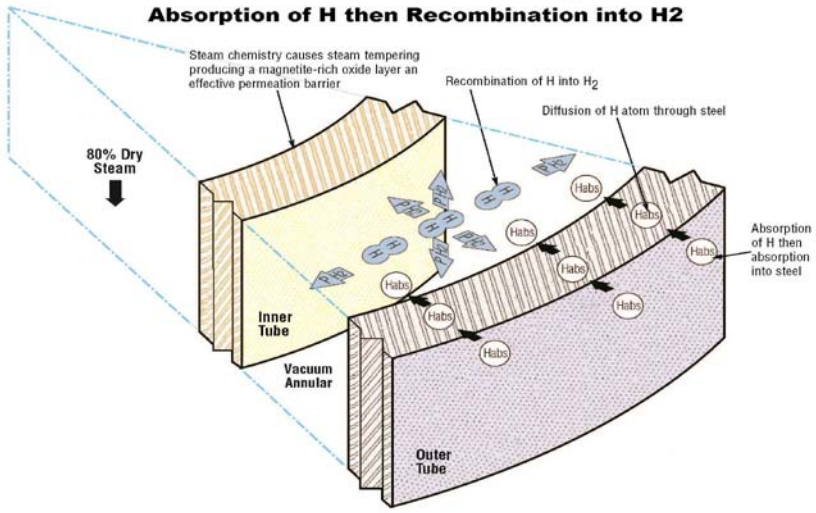
In order for Hydrogen to diffuse through the metal matrix, it must first be absorbed. Absorption is really a multi-step process from either gas or liquid phase. In “gas phase” a Hydrogen molecule dissociates at the metal surface creating two absorbed hydrogen atoms (H). In the “liquid phase”, protons present in the water (wellbore fluids between the VIT joint and casing)

accept an electron from the metal, thus creating an absorbed hydrogen atom (H) at the metal surface.

Once the Hydrogen atoms are absorbed onto the metal surface they may either become absorbed into the metal matrix or recombine with neighboring Hydrogen atoms to form Hydrogen gas. Hydrogen gas is too large a molecule to become absorbed and so bubbles off into solution or diffuses back into the gas phase.

If Hydrogen atoms are absorbed into the metal, they then diffuse from the entering to the exit surface where they become desorbed into the annulus between the inner and outer tube (the vacuum space). The same reactions govern desorption as do absorption, only they occur in reverse, therefore the (H) + (H) become H^2. For VIT there is no solution or electrolyte present in the evacuated annular space so only gas phase reactions occur.

In the case of VIT, Hydrogen (H) can permeate through either the inner or the outer tube. Laboratory testing has shown rates of inner tube permeation are sensitive to steam chemistry and are greatly reduced once a joint is put into service because steam tempering creating the production of a magnetite-rich oxide layer which acts as an effective permeation barrier between the inner tube and the evacuated annulus.



Laboratory work shows Hydrogen (H) permeation rates through the outer tube surface into the evacuated annulus can be very large and highly dependent upon the wellbore environment. Most VIT strings will be installed into wells using a thermal packer and expansion joint and generally Petroleum Engineers provide for a dry annulus between the VIT and casing. Correlating laboratory and field data with (H) permeation test data from SAES Getters a Getter quantity is specified for each outer tube outside surface area. Field evaluations and testing of in-service

tubing has been conducted on a limited, and generally this information confirms the findings presented herein.

In 1985, tests of various joints installed into a single cyclic steam well at the Brea Olinda field, California were life cycle tested. These tests were limited to a five (5) year extended life period and provide a single point of reference for expected thermal conductivity coefficients (K) of a typical Vacuum Insulated joint during its first 5-years in both a dry and wet annulus.

Year	Dry Annulus K=Btu/hr-ft-°F	Wet Annulus H^2S = 9 ppb K=Btu/hr-ft-°F
1	0.0035	0.0035
2	0.0035	0.0050
3	0.0040	0.0070
4	0.0050	0.0088
5	0.0063	0.0106

Additional experiments have been performed to investigate the effects of tubing coatings on Hydrogen Permeation rates. The results showed Hydrogen permeation is reduced with a high build aluminized coating on the OD of the outer tube, this being the least expensive method.

Additional work is needed and planned for the evaluation of tubing treatments and coatings to reduce Hydrogen permeation. This work requires both manufacturer and end user cooperation so that any results and recommendations meet the cost constraints of the marketplace.

Vacuum life is based on laboratory work conducted during the development of Vacuum Insulated Tubing by Babcock & Wilcox and independent work performed by SAES Getters. Oil Tech Services installs a quantity of Getter materials into the evacuated annulus of each joint to provide for a 20-year life based on the above presentation.