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## New Advances and a Historical Review of Insulated Steam Injection Tubing

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### Abstract

New high vacuum Gettering technology is being applied in today's Insulated Steam Injection Tubing. After the 1973 oil embargo, the U.S. government funded a number of initiatives to develop equipment and technology that might lead to additional worldwide heavy and unconventional oil resources. "Deep Steam", one of these projects, was funded to develop new technology could be applied heavy oil resources. Two approaches were taken; develop a downhole steam generator, and second, to develop new and improved thermally efficient Insulated Steam Injection Tubing.

Insulated Tubing, developed originally to address environmental concerns associated with permafrost regions on Alaska's North Slope, has evolved and been adapted for use in heavy oil fields around the world to reduce heat losses in steam injection wells, improve economics, and improve efficiency of heavy oil recovery.

This paper describes the evolution of Insulated Steam Injection Tubing: Reasons for using, new advances in High Vacuum Insulation technology, design requirements, review of field test results from past technical papers, and future work to improve the product, technology, and operating life.

### Introduction

Insulated Steam Injection Tubing can benefit both huff-and-puff and steamflooding projects. It will reduce heat losses in the wellbore, especially in deep reservoirs or where steam volumes are relatively low. Reduced heat loss improved bottom hole steam quality, and lowered casing temperatures combine together to improve project efficiency, economics, and reduce the risk of casing failure from thermal stress.

Developed originally to address environmental concerns associated with permafrost regions in Alaska's North Slope oil fields, Insulated Steam Injection Tubing was adapted for steam injection applications in heavy oil fields worldwide. In recent years, Insulated Tubing has evolved for use in offshore oil production as a method to reduce annular pressure buildup in deepwater completions, for cold startups in subsea completions, and to reduce paraffin deposits and keep crude production above the paraffin deposition temperature<sup>1</sup>.

Most Insulated Tubing produced today uses High Vacuum Gettering technology to produce and maintain a High Vacuum Environment in the annulus between the outer and inner tube. Getters are also used to absorb gas contamination in the cases where an inert gas backfilled is used as the insulation medium. This paper will address:

1. Reasons for using insulated tubing.

<sup>1</sup> Vacuum Jacketed Tubing: Past Present, and Future, Mark A. Bunton, P.E. Diamond Power International, Inc., SPE No. 55994

2. Gettering Technology for High Vacuum insulation systems.
3. Design requirements, manufacturing processes, and criteria engineers can use in their selection process to use or not use Insulated Tubing.
4. Historical review of past technical papers concerning Insulated Steam Injection Tubing.
5. Future work and testing that might lead to improvements in the technology and product.

### Reasons for use

Thermal projects will use both conventional steam generators and cogeneration to produce high temperature steam for injection. Generally this equipment produces 80% quality dry steam from feedwater with relatively high concentrations of total dissolved solids. In all cases the feedwater is free of hardness, iron, silica, and oxygen.

As a rule-of-thumb, heat loss from properly insulated above ground surface line, from steam generator to steam injection wellhead, is about 120 to 135 Btu/Hour per (30-34 kcal/hr) linear foot depending on line size, insulating thickness, surface treatment, and outside ambient temperature. Unless steam volumes are relatively low or the distance from generator is great, surface line heat losses are generally not taken into account, and wellhead steam quality is normally assumed to be the same as the output from the Steam Generator.

Heat loss is a function of pipe size, insulation quality, steam temperature (pressure), and the ambient temperature of the surrounding environment. Heat is transferred by the mechanisms of (1) Conduction; (2) Convection; and (3) Radiation. In practice, when engineering an insulation system all three of these mechanisms of heat transfer are addressed. For High Vacuum Insulated tubing, radiation heat loss takes priority.

In most thermal enhanced oil recovery projects, because of the nature of steam generation equipment, we have two-phase flow. Both water and steam phases, have different Enthalpies based on steam temperature (pressure). Enthalpy values are available from published tables.

In considering our option to use or not use Insulated Tubing we use Enthalpy values, steam temperature (pressure), steam flow rates, and well depth to evaluate the expected performance for a steam well.

Reservoir Engineers simulate reservoir behavior based on specified bottom hole steam quality. It is therefore critical to know and control heat loss from the injection string. In practice, a reduced steam quality from forecasted reservoir modeling could impact the success and economic survival of a new steam project.

Because the rate of heat loss is a function of steam temperature (pressure) and insulation properties, the absolute energy loss (quantity of BTU lost per hour per foot) will be the same for a low steam flow rate as for a full design. This is an important point to remember: The energy loss at low flow rates comes from a smaller quantity of steam, and therefore the relative energy loss per unit of mass is greater. These higher energy losses at low steam flow rates substantially reduce steam quality at the bottom of the well.

### Steam Quality

In addition to Enthalpy values, steam temperature (pressure), steam flow rate, the variables used to calculate the heat loss and resulting steam quality change are:

- Borehole diameter
- Casing size and weight
- Tubing size and weight
- Insulated Tubing outer tube and inner tube sizes and weights
- Insulation k-value<sup>2</sup>

Ramey<sup>3</sup> and Satter<sup>4</sup> and others have developed heat loss equations for steam injection wells that have become a basis for most software programs. Industrial Technology Management,

<sup>2</sup> Thermal conductivity,  $k$ , is the property of a material that indicates its ability to conduct heat. It is defined as the quantity of heat,  $\Delta Q$ , transmitted during time  $\Delta t$  through a thickness  $L$ , in a direction normal to a surface of area  $A$ , due to a temperature difference  $\Delta T$ , under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

<sup>3</sup> Ramey, H. J. Jr., Wellbore Heat Transmission. Journal of Petroleum Technology, Vol 14, No. 4, April 1962, pp 427.

<sup>4</sup> Satter, Abdue, Heat Losses During Flow of Steam Down a Wellbore, Journal of Petroleum Technology, Vo. 17, No. 7, July 1965, pp. 845-851.

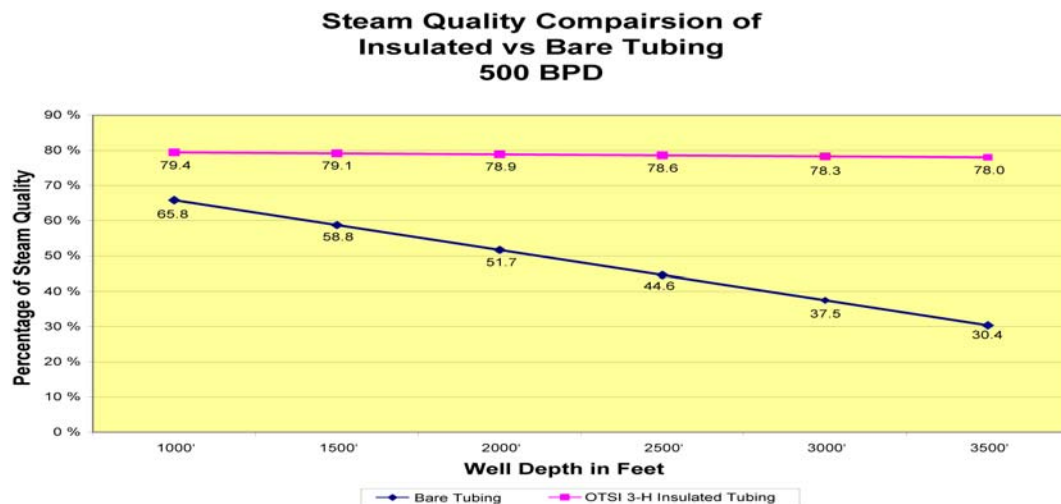


Figure 1

Inc. (ITM), and Oil Tech Services, Inc. (OTSI) use a proprietary software program to make these calculations and forecast bottom hole steam quality. Figures 1, 2, and 3 illustrate heat loss and bottom hole steam quality in typical steam injection wells. These charts can be used as a general guide to estimate heat bottom hole quality vs. depth and steam flow rates. The data represented in all three charts are for 2-7/8" (73.025mm) bare tube, and 4-1/2" x 2-7/8" (114.3mm) x (73.025mm) Vacuum Insulated Tubing. The well is with 7" (177.8mm) x 23 pound casing cemented to the surface. The borehole is 9-5/8" (244.475mm) borehole. The calculations include a thermal packer and expansion joint at the bottom of the injection string. Validation of software programs used to forecast heat loss and bottom hole quality are confirmed by field testing by industry and the U.S. Department of Energy<sup>5</sup>

All three charts illustrate that Vacuum Insulated Tubing will substantially reduce heat losses and thereby improve bottom-hole steam quality compared to bare pipe. The most significant variance between bare and Vacuum Insulated Tubing is in deep wells (wells with depth greater than 1,800 feet – 548 meters) and in low steam flow installations. Demonstrating once again, "Because the energy loss at low flow rates comes from a smaller quantity of steam, the relative energy loss per unit of mass is greater."

<sup>5</sup> Overview of an Instrumented Steam Injection Test Program, B. Traynor, V.R. Brown, Kawasaki Thermal Systems, Inc.; T.R. Fraizer, Texaco, Inc.; T.B. Reid, U.S. DOE, SPE No. 21525

Figure 1 – Low Steam Flow Case (15 gpm – 57L/hr): At 1,000-feet (304.8m) the variance between insulated and non-insulated tubing is 13.6% and grows to 47.5% at 3,500-feet (1066.8m) depth. Examining the percentage of steam quality for each type of tubing we see that bare tubing experiences a 35.4 % degradation in steam quality from the 1000 to 3,500-feet (305-1067m) depth, where with insulated tubing steam quality remains nearly the same.

Figure 2 & 3 – High Steam Flow Cases: Although not as pronounced, the results are similar.

#### Gettering Technology for High Vacuum Insulated Steam Tubing, and New Getter Materials

High vacuum insulated tubing uses Non-Evaporable Getters (NEGs) as a reactive material to ensure an effective long-term thermal insulation system, NEGs are used to pull (pump) and maintain the high vacuum in Vacuum Insulated Tubing to a vacuum level in the  $10^{-6}$  Torr range. NEGs are very reactive materials, generally made of zirconium, titanium and their alloys, which dissociate and trap, in the form of stable chemical compounds, gas molecules impinging on their surface. These NEGs are optimized for the application by choice of the chemical properties, size, configuration, and placement within the system. Common shapes and configurations (e.g. pills, tablets, washers, strips) are shown in Photo 1.

NEGs remove all active gases, including oxygen, nitrogen, moisture, carbonmonoxide, carbon dioxide, hydrogen, with a much lower

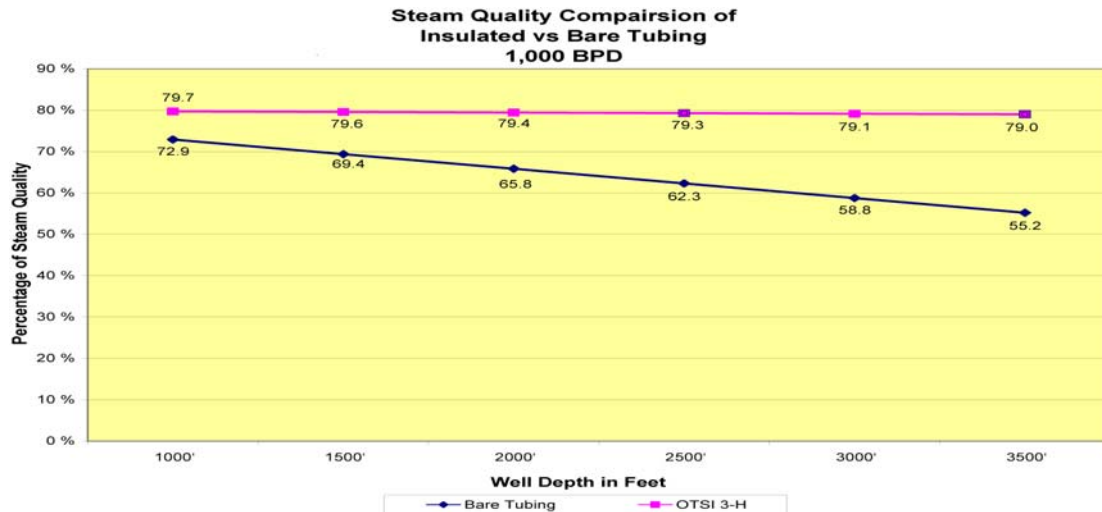


Figure 2

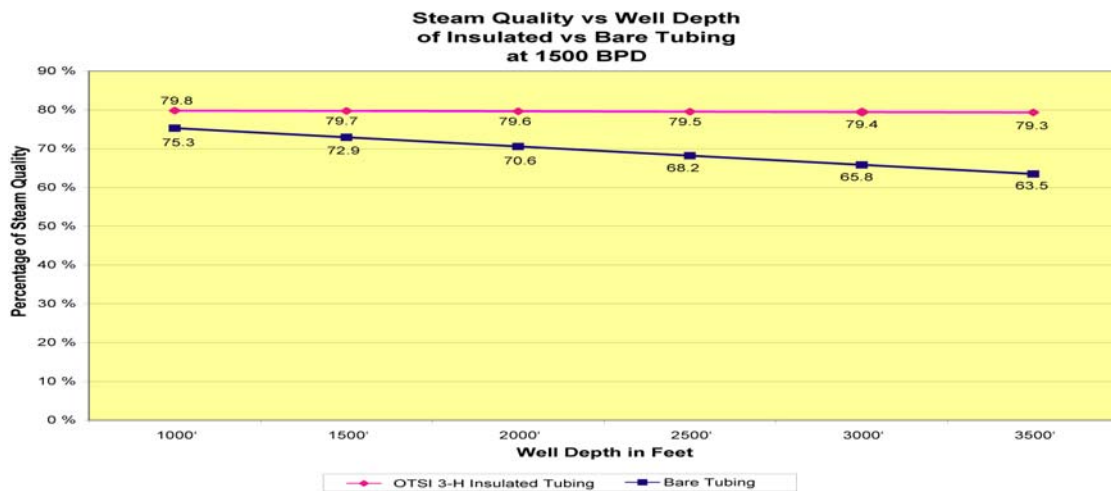


Figure 3

capacity, hydrocarbons. They do not react with, nor sorb noble gases (such as argon typically used in gas backfilled insulated tubing, making NEG's a viable option to include in this type of system when corrosion and gas permeation are expected). Differently from physical absorbents, such as active charcoal, silica gel or molecular sieves, NEG's sorb gases irreversibly. From a practical point of view, this means that once a molecule is trapped on the getter surface it cannot be released again, even if the Getter is heated at high temperature. The only exception to this general behavior is hydrogen, which generates an equilibrium pressure that depends on temperature. For typical getters used in thermal insulation, hydrogen is removed extremely effectively at ambient temperatures (65-80°F) and even at higher temperature the equilibrium pressure generally stays at a much lower level than required to maintain adequate insulating properties. NEG's offer very good

trapping efficiency for hydrogen at all operating temperatures making them an ideal solution for High Vacuum Insulated Tubing for use in steam injection and offshore oil production wells.

In the case of Vacuum Insulated Steam Injection Tubing, a high vacuum of  $10^{-5}$  to  $10^{-6}$  Torr is required to avoid heat transfer by gas convection, and must be maintained for the entire lifecycle of the product. Keeping such a vacuum level over several to tens of years is far from trivial. Gas desorption from all the surfaces exposed into the vacuum takes place over time, progressively increasing the internal pressure and the heat transfer by gas conduction.

Careful pre-treatments of the inner and outer tubes by sandblasting, chemical cleaning of internal layers of aluminium foil, selecting

insulating materials that will not outgas, proper gas purging by mechanical pumping, and long-term high temperature vacuum bake-out are key elements in the manufacturing process all engineered to the goal of reducing overall long term out-gassing. However, even in the most controlled manufacturing process, a non-negligible residual out-gassing rate is unavoidable and must be taken into account in engineering the insulation system and selecting the type and quantity of NEG's used.

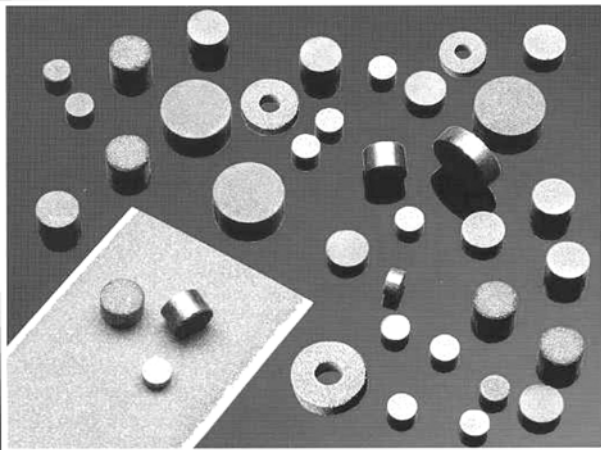


Photo 1 Examples of various Non-Evaporative Getter – NEG configurations

To sorb gases, NEG's must be "activated". The activation process is carried out after establishing a vacuum by mechanical pumping and heating. When the mechanical pumping process is completed the getter is activated at a specified temperature over a specific period of time. This treatment allows surface oxides and carbides passivating the surface to decompose and diffused inside the NEG's lattice structure, leaving a clean and reactive metal surface, available to gas sorption.

The effect of the activation temperature and time in the case of the SAES ST707<sup>®</sup> Getter (the typical getter for Vacuum Insulated Steam Injection Tubing) is shown below. In the case of ST707 full activation is achieved at 450°C (840°F) in about 10 minutes, and a longer period at lower temperatures.

When Vacuum Insulated Tubing remains out of service either in the well or in storage, the getter surface will become covered with dissociated molecules, and its pumping speed will drop until the Getter is re-activated to restore pumping

performance. Once the insulated string is installed into a steam injection well, this reactivation will occur during the first few minutes of steaming depending on steam temperature. This re-activation process can be repeated time and time again without harm or degradation to the getter. During this re-activation process dissociated atoms diffuse from the surface into the bulk, thereby increasing the pumping speed and providing extra gas sorption capacity.

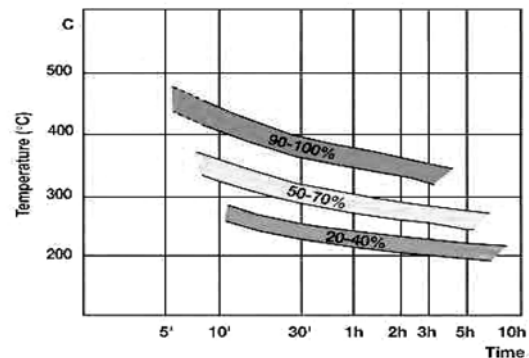


Figure 4 Getter activation efficiency curves for ST707, shown in minutes and hours

A recent advance in Gettering technology exploiting the temperature effect is SAES St 2002<sup>®</sup> (Zr 70%-V 15%- Mg 8,7%-Fe-RE 3%). St 2002<sup>®</sup> is particularly suited for Vacuum Insulation systems in non-steam applications because of its lower activation temperature (about 100°C [180°F] lower temperature than St707) with similar sorption speeds and capacity for gases. Providing a lower activation temperature, St 2002<sup>®</sup> will pump gases at moderate temperatures of 150-200°C (300-400°F). This lower temperature characteristic is ideally suited for Vacuum Insulated Tubing for deep offshore oil production wells.

#### Design requirements, manufacturing processes, and selection criteria

Vacuum Insulated Steam Injection Tubing is a welded, prestressed structural system. The inner tube is welded concentric with an outer tube casing to form a sealed insulating annulus. The typical thread is a Buttress thread with API modified coupling, (seal ring groove and high temperature Fluorocarbon seal ring), made power tight to one end of each joint and ready for installation into an injection well. When shipped, both pin and coupling threads are protected with corrosion protective coating and a composite thread protector. The outer tube is protected with a corrosive resistant aluminum

base coating.

Manufacturing and assembly is in a clean environment with great care is taken to insure cleanliness of all materials and surfaces. Small amounts of contamination or oils induced during assembly of insulated tubing can cause problems during the vacuum process.

The insulation is a high vacuum gettered insulation system consisting of multiple layers of aluminum foil separated by insulating paper wrapped around the inner pipe. Getter is strategically installed to take advantage of the highest temperature surfaces. The inner tube is installed into the outer tube and both ends are welded and heat-treated. The tubing is prestressed in a proprietary apparatus then welded, leaving the inner tube in tension and the outer tube in compression. Prestressing compensates for differential expansion of the inner and outer tubes and minimizing the total thermal expansion of the injection string. After welding and prestressing the tube is placed in an oven, connected to mechanical vacuum pump through a port located at one end of the tubing, and baked at high temperature (230°C - 450°F). The insulated annulus is mechanically pumped, outgassing the insulating materials and steel to a pressure of approximately 10 microns (0.01 Torr). During this outgassing process the getter is cool and below its activation temperature. When the mechanical pumping process is completed, oven temperature is increased to allow activation of the getter. After activation and while the tubing is hot, the evacuation port is plugged and seal welded. Tubes are moved out of the oven and into test where thermocouples are placed inside and outside the tubing, temperature readings are taken and each individual tubes conductivity value is calculated and recorded with the tube tally. Each joint has a unique serial number.

The standard product will use API 5-CT Grade L-80 for the inner tube and Grade J-55 for the outer tube. Collars are J-55.

Coupling heat loss is minimized by placement of a coupling insulator fitted into the coupling cavity between two joints. The coupling insulator incorporates a specially fabricated fluorocarbon material molded over a metal sleeve having an ID to match the ID of the inner tube.

Typical thermal performance (conductivity)

values are:

Main Body	0.003
Coupling with Insulator	0.118
Full Joint including Coupling	0.0018

**Thermal Conductivity BTU/Hr-Ft-°F  
at 650°F (average)**

Conductivity values for each joint are measured and recorded after manufacturing.

**History, Field Studies, and Published Results of Insulated Steam Injection Tubing**

The Application of Insulated Steam Injection Tubing dates back to about 1965, during the early developments on the North Slope, Alaska. The insulated strings were production tubing used to maintain crude production temperatures and protect surrounding layers of permafrost. The result was that the temperature variation was not substantially significant to warrant insulated tubing.

After the 1973 oil embargo there were many financial incentives to pursue heavy oil resources worldwide. Early steam projects were commenced in California, Canada, and Venezuela. Major activities continued worldwide until about 1989, when price incentives to recover this difficult to produce resource disappeared. Since 1973, Oil Companies, Manufacturers, and Governments have conducted a number of field and laboratory studies to evaluate various thermal recovery methods including proof of performance for Insulated Tubing.

Generally Vacuum Insulated Steam Injection Tubing is deployed into three different types of steam injection wells. The first method is a Conventional well where a hole is bored, casing inserted and cemented to surface, followed by a single string of bare or insulated tubing into an open annulus sealed at the bottom, above the production zone, by a thermal packer and expansion joint. The second method is a multi-string application whereby one or more tubes are installed into a single well (completed by conventional practices above) with the intent to simultaneously steam different formation sands. This type of installation may include a combination of both Insulated Tubing and Bare Tubing. The third and final practice, one the authors believe may offer substantial financial

incentives for oil producers, is a Slimhole<sup>6-7-8</sup> completion whereby a small bore hole is drilled and Vacuum Insulated Steam Tubing is installed and then cemented in place to surface. The only major disadvantage is the difficulty of well workovers and repairs to the production zone because of the reduced tubing ID size, typically being 3 to 4-inch ID.

Validation of steam quality performance presented in figures 1, 2, & 3 occurs in the 1985 study by J. W. Galate and R. T. Michell III, Enertech Engineering & Research, SPE 13622<sup>9</sup>. In case 3 of their paper they determined insulated tubing produced the least heat loss and highest steam quality of 77.8% approximating the quality percentages presented herein. Their paper concludes Insulated Tubing was 98.4% thermally efficient from surface to bottom hole.

In 1987, G. Paul Willhite and Suzanne Griston (Castrup)<sup>10</sup> study wellbore refluxing examining methods for reducing its detrimental thermal effects in conventional steam injection wellbores. The study uses Inert gas backfilled type insulated tubing with high efficiency collar inserts. The paper offers strategies to reduce refluxing, including removal of annulus water with an N<sub>2</sub> blanket prior to setting the packer, and continuous pressurization of the annulus. In their comparison of condition data they illustrate heat loss data for refluxing and non-refluxing wells. Several earlier papers and field tests address the efficiency of Insulated Tubing in steam injection wells and the reflux phenomena presenting the same conclusions

<sup>6</sup> Slimhole Drilling Saves Dollars in Thermal Injectors, G.A. Grove and A.W. Vevloet, Unocal Corp, SPE No. 25780

<sup>7</sup> Project Design for Slimhole Steam Injectors in Thermal Recovery Projects as Compared to Conventional Steam Injections, by E.L. Dennis, SPE, Chevron USA Company, SPE No. 29629

<sup>8</sup> Recommended Practices for Slim-Hole Steam Injectors by Suzanne Griston Castrup, SPE, Integrated Sciences Group, SPE No. 68808

<sup>9</sup> Downward Two-Phase Flow Effects in Heat-Loss and Pressure-Drop Modeling of Steam Injection Wells, by J.W. Galate and R.F. Mitchell III, Enertech Engineering & Research Co., SPE No. 13622

<sup>10</sup> Wellbore Refluxing in Steam-Injection Wells by G. Paul Willhite, SPE University of Kansas and Suzanne Griston, SPE Chevron Oil field Research Company, *JPT* March 1987, SPE No. 015056

and recommendations stated in the Wilhite and Griston paper<sup>11-12</sup>.

The effective use for a non-corrosive gas blanket in the tubing/annulus of a steam injection well is demonstrated in SPE 01703 - Effective Design of Insulated Tubing for a Sour Environment, Ken Cormier, Shell Canada, Ltd.<sup>13</sup>, and SPE 18810 The Use of Insulated Tubing in Thermal Projects<sup>14</sup>.

### Conclusion, Future Work and Testing

Vacuum Insulated Steam Injection Tubing is a viable option for steam injection projects, and becomes especially important for the success of a steam EOR project when depths are greater than 1,800-2,000 feet, and/or when steam flow rates are relatively low.

Vacuum Insulated Tubing is a viable option for deep offshore oil and gas production, where produced temperature is an issue, whereby low temperature produced fluids create production problems including hydrate, paraffin, and wax formation in production tubulars.

State of art High Vacuum Technology using appropriate Getter materials provide a suitable insulation system provided the tubing is properly engineered the producer incorporates proper manufacturing processes including:

- Manufacturing cleanliness.
- Long-term High Temperature Bakeout to outgas all surface gases from all raw materials.
- The proper number of radiation barriers (reflective surfaces) inside the insulated annulus to minimize radiation heat losses.
- Installing the right amount of Getter, based on both field and laboratory work, including a forecast for both long-term

<sup>11</sup> Thermal Efficiency of a Steam Injection Test Well With Insulated Tubing, by D.P. Aeschliman, Sandia Natl. Laboratories, R.F. Meldau and N.J. Noble, Husky Oil Operations, Ltd., SPE No. 11735

<sup>12</sup> The Effect of Annulus Water on the Wellbore Heatloss From a Steam Injection Well With Insulated Tubing, D.P. Aeschliman, Sandia Natl. Laboratories, SPE No. 13656

<sup>13</sup> Effective Design of Insulated Tubing for a Sour Environment, Ken Cormier, Shell Canada, Ltd. August 1987, SPE No. 017103

<sup>14</sup> The Use of Insulated Tubulars in Thermal Projects, A.R. Kutzat, D.W. Gunn, Mobil Oil Canada, SPE No. 18810

materials outgassing and gas permeation.

- Proper Getter selection and placement within the annulus insulation system to ensure multiple reactivations during the life cycle of the tubing. This selection will be based on known operational temperatures for steam or for produced fluids in the case of deep offshore production.

Future work is needed in two areas. First on methods, technology, and tools to cause a dry annulus environment above a thermal packer and between steam injection tubing and casing. A wet annulus will affect steam performance because of the reflux phenomena whereby wellbore water is boiled and condensed on cooler sections of the insulated string over-and-over causing the wellbore to never become completely void of water.

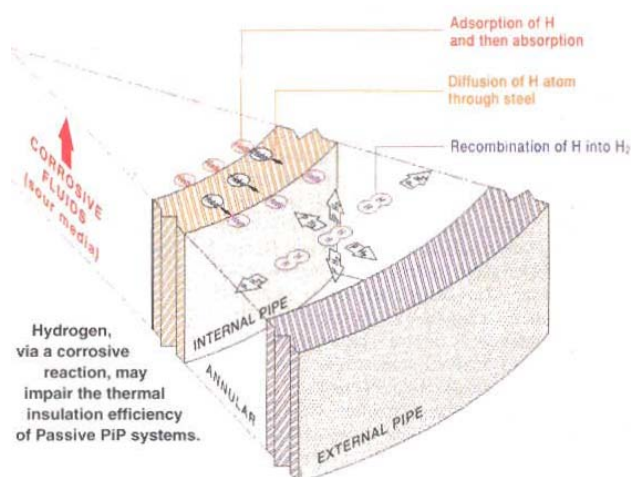


Figure 5  
Hydrogen Contamination

Second, to develop a better understanding of the corrosive environment Vacuum Insulated Tubing is subjected in both steam injection and deep water offshore production wells. Corrosion on inner and outer tubing can result in hydrogen permeating<sup>15-16</sup> through the walls of the tubing and into the insulated annulus between outer and inner tubes. (See figure 5.) Hydrogen

permeation beyond the sorption capacity of the Getter will cause degradation in thermal performance because of loss of vacuum. Possible solutions to this issue are barrier coating. Some work has been done in this area relative to use of aluminum-rich coatings.

<sup>15</sup> Effective Design of Insulated Tubing for a Sour Environment, Ken Cormier, Shell Canada, Ltd. August 1987, SPE No. 017103

<sup>16</sup> The Use of Insulated Tubulars in Thermal Projects, A.R. Kutzat and D.W. Gunn, Mobil Oil Canada, SPE No. 18810