



OIL TECH SERVICES, INC.
Industrial Technology Management, Inc.

18815 Crenshaw Blvd., Ste. A

Torrance, CA 90504

(310)-527-2695

Email: mlombard@itmreps

Website: www.itmreps.com

INTERNAL TECHNICAL DOCUMENT

Subject: Thermal Stress on Welds and Tubing during the Bake-out Process

Tube Size: 4-1/2" x 3-1/2" (2.992 ID of inner tube)

Introduction:

The bake-out process for vacuum insulated tubing is a combination of several operations performed to achieve a high vacuum sealed within the annular space between the inner and outer tube of Vacuum Insulated Steam Injection Tubing.¹

The bake-out process, because of the differential temperatures applied to the inner tube during the oven cycle, and the significant differential temperatures during cool down after tubes are removed from the oven, apply significant stress on the inner and outer tubes and the weld connecting the two tubes. This report summarizes the bake-out process and attempts to quantify the thermal stress on the welds and tubing.

Background:

The processes necessary for manufacture of high quality Vacuum Insulated Steam Injection Tubing:

- Cleaning
- Assembly (Installation of GETTER materials into the annulus space)
- Welding
- Vacuum Bake-out
- Sealing
- Testing

¹ The inner and outer tubular contain objectionable gases such as oxygen, carbon monoxide, hydrogen, and nitrogen that will outgas into the vacuum annular space during the life of the product: Outgassing into the annular in substantially increased at elevated steam temperatures. A controlled bakeout cycle including a smooth ramping up to a desired temperature, holding at the desired temperature, and a smooth ramping down is known method of outgassing the surface of such steel. This process is both temperature and time dependent. Reducing material outgassing is essential to achieve an extremely high vacuum.

Equipment used in the bake-out process:

- High temperature oven with programmable controllers
- Vacuum port tool (Specially designed port closure tool for sealing port)
- Vacuum cart with manifold, valves, gauges, and vacuum pump
- Hydraulic hand pump
- Fan-manifold assembly and metal hoses

Cleaning of all raw materials:

In order to reduce the quantity outgassing during the vacuum bake-out process the oils, greases, and other volatile hydrocarbons are removed by cleaning processes. Sandblasting to white metal cleans the outer tube I.D. Sandblasting to white metal cleans the inner tube O.D. The raw materials for the internal insulation system, consisting of aluminum foil and insulating paper are specifically selected for cleanliness and low outgassing.

GETTER Installation:

GETTER is installed next to the inner tubing while the multi-layers of AL foil and insulating paper are wrapped around the inner tube. For Vacuum Insulated Tubing a high temperature GETTER is selected so the steel materials can be outgassed at elevated temperature without premature GETTER activation.

Prestress of Inner Tube:

During the manufacturing process, the inner tube is prestressed inside the outer tube. The prestress is designed to overcome the thermal expansion differences between the inner and outer tubes. Prestressing on the inner tube is 21,712 psi in tension, while the outer tube is in compression. The actual values are proprietary.

Assembly and the Vacuum Bake-out (outgassing) process:

After assembly, with the inner tube inside of the outer tube, both ends are welded using the Automatic Gas Tungsten Arc (GTAW) process. Joints are racked into a high temperature gas fired convection oven. The vacuum pump connection tool is positioned over the vacuum port existing at one end of each outer tube; the tool is secured and leak tested to confirm "zero" leakage around the vacuum tool.

Additional note: An integral part of the port tool is seal pin assembly: This assembly holds a port plug that is mechanically installed into the vacuum port when the bakeout process is completed. This port plug is seal welded once installed using a manual GTAW process.

After all vacuum tools are installed and the operator has confirmed "zero leakage", valves are opened to the vacuum pump is started. The oven is started the time-temperature cycle program is commenced. The first part of the bakeout process is at an oven temperature below the GETTER activation temperature. This temperature allows a controlled outgassing of surface gasses in steel and insulating materials being pumped by the mechanical vacuum pump. At a time point in the bakeout cycle, confirmed by

data that the vacuum pump has mechanically removed as much gas as possible, the oven temperature is ramped up to the GETTER activation temperature establishing the high GETTER maintained vacuum.

Based on a timed activation cycle, both inner and outer tubes are caused to heat to the required GETTER activation temperature (above 600°F). Once this cycle is complete, vacuum level is measured at each vacuum tool. At the proper vacuum level the bake-out and GETTER activation process is completed and the vacuum port is plugged and seal welded.

Sealing:

Once the desired vacuum level is achieved and confirmed, the seal plug, pre-installed within the vacuum port tool, is pressed into the vacuum hole. The vacuum tool is removed and the seal plug is seal welded (TIG welded) around the pin circumference to insure long-term sealing.

Discussion of Thermal Stress on Tubing and Welds during and after the Bake-out Cycle:

Actual oven temperatures and the back-out time cycle are proprietary process and not disclosed herein, but it is reasonable to assume at certain points in the bake-out process there is a differential temperature between of inner and outer tube of 500°F to 800°F.

Thermal stress is a function of differential temperature, coefficient of thermal expansion and modules of elasticity of the materials. For this purpose, we assume a 600°F (333.3° C)² temperature differential between inner tube and outer tube shortly after removal of tubes from the oven.³ This temperature differential is caused by the rapid cool down of the outer tube to ambient temperature, while the inner tube remains hot because of the high efficiency of the vacuum insulation system, the only mechanism of cool down of the inner tube being air flow through the ID.

² The bake-out process is a controlled ramp-up and hold to the desired temperature and a controlled ramp down before removal from the bakeout oven. After removal from the bake-out oven the outer tube will cool to ambient temperature very quickly, while the inner tube will remain at an elevated temperature for a considerable period of time due to the insulating performance of the high vacuum insulation system.

³ SPE Paper No. 112981, New Advances and a Historical Review of Insulated Steam Injection Tubing, page 5, GETTER activation temperatures. Maximum GETTER activation temperature is 850°F (450°C) for Saes ST708 and lower for some other GETTER compounds. The temperature value used above is conservative and based on manufacturing experience.

According to JFE Steel Corporation literature⁴, the coefficient of thermal expansion is 8.64×10^{-6} per inch per inch, and the Young modulus of elasticity of material is 32,000,000 psi. Therefore the combined thermal stress for the two tubes is:

$$(8.64 \times 10^{-6})(600^{\circ}\text{F})(32,000,000) = 165,000 \text{ psi}$$

This stress will be distributed inversely proportional to the area of the weight of each tube. The 4-1/2" outer tube is 11.6 pounds/foot, the 3-1/2" inner tube is 9.5 pounds/foot. The combined weight is 21.1 pounds/foot. The 4-1/2" OD x 4" ID outer tube has a cross sectional area of 3.34 in², and the 3-1/2" OD x 2.992" ID inner tube has a cross sectional area of 2.59 in², for a total area of 5.93 in².

$$\text{Outer tube stress} = (165,000) (2.59/5.93) = 72,065 \text{ psi} - 21,712 \text{ psi}^5 = 50,353 \text{ psi} \\ \text{(tension)}$$

$$\text{Inner tube stress} = (165,000) (3.34/5.93) = 92,934 \text{ psi} - 21,712 \text{ psi} = 71,222 \text{ psi} \\ \text{(compression)}$$

The above calculated thermal stress values are the extreme case and based on the high oven temperature of GETTER activation (600°F): This will probably be the highest and most extreme stress contention the product will encounter during its life.

Because of the above values, Oil Tech Services uses a J55 outer tube and a L80 inner tube. The high compression stress on the inner tube during GETTER activation could cause the inner tube to corkscrew or collapse.

Some manufacturers will use J55 tubing on both the inner and outer tubes. This tube material selection would indicate one or more of the following:

- A higher prestress value on the inner tube,
- Lower bakeout oven temperature⁶,
- Manufacturing process that cools the inner tube and outer tube simultaneously so the temperature differential between inner and outer tube is kept nearly identical.

⁴ JFE Steel Corporation, 0510R(0508)1-1 UM

⁵ Prestress Value

⁶ SPE Paper No. 112981, New Advances and a Historical Review of Insulated Steam Injection Tubing, page 5, GETTER activation temperatures.

A lower bake-out temperature would reduce the effectiveness of the outgassing process and likely result in an inferior product and reduced life cycle and/or the necessity of installing addition GETTER to compensate for higher rates and volume of outgassing during the products life cycle.

Stress on Connection Weld between Inner and Outer Tube during and after bakeout cycle:

The stresses on connection welds between outer and inner tubes during and after the bakeout cycle are also higher than the product will probably ever see during its life cycle. These stresses are calculated below:

Weld area (based on fillet weld at face of the inner tube being about 3/8-inch high) is approximately 3-7/8" OD x 3-1/8" ID = 4.123 in².

$$\text{Force on Welds} = (2.59 \text{ in}^2)^7 (71,222 \text{ psi})^8 = 184,465 \text{ pounds}$$

$$\text{Weld Stress} = 184,465 \text{ pounds} / 4.123 \text{ in}^2 = 44,740 \text{ psi}$$

This stress is below the allowable well stress for the selected materials.

Proof of Weld Integrity: The 168,179 pound force on weld and 40,790 psi weld stress thermally induced into each weld due to the bake-out and cooling process is a significant event: If any weld failed or suffered from welding process problems it would cause vacuum failure and would be immediately detected during K-Factor testing, the next process in the manufacturing cycle. Therefore the K-Factor test is a comprehensive test of both performance and product integrity at the end of the manufacturing cycle.

⁷ Cross sectional area of Inner Tube.

⁸ Compressive stress on Inner Tube.