In-service helium leak testing of vacuum furnace

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Abstract. Helium leak detection of vacuum furnaces and equipments used for processing of nuclear material is generally carried out by utilizing vacuum spray technique. In this technique helium leak detector is connected to the furnace, back ground reading is noted and helium gas is sprayed on all the suspected joints. Any increase in back ground is noted as leak signal. Processing of Zirconium alloy cladded fuel pins is carried out in vacuum furnace of about 3 meter length and 500 mm inside diameter. Furnace is connected with two numbers of rotary vacuum pump and one number of diffusion pump for creating vacuum (1 x 10^{-6} torr ) inside the furnace. It is desirable that furnace should have good vacuum and best possible leak tightness during dynamic and static vacuum. During dynamic vacuum at higher temperature although required vacuum is achieved the furnace may have fine leakage through which air may enter and cause oxidation of clad tube leading to change in its coloration. This change in coloration will cause rejection of fuel element. Such fine leakages may not be reflected in the dynamic vacuum of the system at high temperature. During trial run change in coloration of outside surface of clad tube was observed although dynamic vacuum of the furnace was in the range of 1x10^{-6} torr range. To eliminate such possibilities of oxidation due to fine leakages in the system, it was decided to carry out in-service leak testing of the furnace. Helium leak testing of the furnace was carried out by using vacuum spray method and leaks observed were repaired and furnace was retested to ensure the leak tightness. The in-service helium leak testing of the furnace helped in maintaining its leak tightness during service under dynamic vacuum and prevent oxidation of fuel element. This paper describes the techniques of in-service helium leak testing, it’s importance for detection of fine leak under dynamic vacuum and discusses details of the testing method and result obtained.

1. Introduction

Leak detection forms an important part of quality control step in chemical, petrochemical, fabrication and nuclear industry. Designer’s have been specifying leak tightness as per different codes like ASME, ASTM, BIS etc. as required by their intended use. In nuclear industry because of radioactive hazard considerations leak tightness in many furnaces and equipments are specified up to 1x10^{-9} std.cc/sec. Helium leak testing of enclosed chambers are carried out to ensure the high degree of leak tightness in nuclear industry. There are generally four ways of carrying out helium leak detection namely vacuum spray method, pressure sniffer method, pressure vacuum method and back pressure filling or bombing method. Helium leak testing of vacuum furnaces and equipments are carried out by using vacuum spray method.
2. Leak Detector
In the present work Console model Helium Leak Detector (HLD) has been used. The basic principle of helium leak detector is based on mass-spectrometer, which is kept under high vacuum of the order of $10^{-5}$ torr. Helium atoms entering in the mass-spectrometer from the leak are first ionized by bombardment of electrons and the positive ions so created are accelerated by an electric field and the ions are separated from each other depending on their mass, by application of magnetic field over it. The helium ions follow a definite path. A slit is used to allow selectively only helium ions. These ions are collected at an electrometer tube, which generate a signal in mili-volt range in proportion to leak rate. The signal is then suitably amplified and displayed on a digital LED display or can be coupled to data acquisition computer through RS-232 port provided in the helium leak detector.

![Fig. 1. Schematic of Helium Leak Detector](image1)

![Fig. 2. Schematic Diagram of Mass Spectrometer](image2)
Figure 1. gives the layout of typical helium leak detector and figure 2. gives the schematic of mass-spectrometer tube. It consists of 2 nos. of roughing pump each of 20 m³/hr. pumping capacity and a 130 litre per second hybrid-turbo molecular pump. The detector has measurement range of 2x10⁻¹¹ to 1x10⁻¹ mbar l/sec. of helium. Two standard permeation type calibrator namely internal and external calibrators do calibration of helium leak detector. In auto mode the detector calibrates itself using internal calibrator of 1x10⁻⁷ mbar l/sec. and only if it is satisfactory gives green signal for further operations. For external calibration of helium leak detector a reference leak standard with leak rate in the range of 1x10⁻⁸ to 1x10⁻⁹ mbar l/sec. may be used.

3. Vacuum Furnace
The vacuum furnace has a large size diameter of about 500 mm x 3 meter height. It is used for processing of fuel elements made of Zirconium clad tube. The furnace is designed to achieve around 1000°C temperature and 1x10⁻⁵ torr vacuum. The vacuum system consist of two numbers of rotary pumps of pumping speeds of 90 CFM and 15 CFM respectively and one diffusion pump of 250 LPM pumping speed. The layout of the furnace is shown in the figure 3. The heating in the furnace is carried out by using seven numbers of circular heaters mounted around the furnace and one number plate type of heater below the furnace.

| No | Description            |
|----|------------------------|
| 1  | Leak Joint - 1         |
| 2  | Leak Joint - 2         |
| 3  | Leak Joint - 3         |
| 4  | Leak Joint - 4         |
| 5  | Internal Leak in V6    |
| 6  | Internal Leak in V3    |

| Vacuum Pump | Pumping Speed |
|-------------|---------------|
| DP          | 3000 l/sec    |
| RP-1        | 7500 l/min    |
| RP-2        | 15 m³/hr      |

Fig. 3. Helium Leak Testing of Vacuum Furnace

4. Leak Detection Procedure
The helium leak detector was connected to vacuum furnace as shown in figure 3. The leak detection was carried out by using vacuum spray method. The dynamic vacuum of the furnace achieved was about 1 x 10⁻⁶ torr. Initially helium leak testing of the furnace was carried out in gross mode and helium gas was sprayed over all the joints like- flanges, tube fitting connectors, gauge head joints etc. more than fifty joints were sprayed with helium gas throughout the furnace one by one by keeping sufficient time to
stabilize the reading, leak was observed in only one joint identified as joint no-1, which was taken up for repair. After repairing of the leaky joint re-testing of joint-1 was carried out in gross test mode and no leak signal was observed and then fine leak testing of the furnace was planned and carried out by using vacuum spray method. Helium gas was sprayed over all the joints mentioned above numbering more than fifty throughout the furnace one by one by keeping sufficient time to stabilize the reading. All the detected leaky joints were covered by the cello tape to avoid false leak signal during testing of further joints. Six joints showed clear leak indication beyond the back ground reading, these joints were repaired and again helium leak tested after the repair. The results have been provided in the table-1. The helium leak detector was calibrated with a standard calibrator of standard leak 1.2 x 10^(-9) mbar l/sec. of helium before and after the test cycle.

| Sr. no. | Leak Location | Back ground reading (m bar l/sec) | Reading after helium gas spray (m bar l/sec) | Reading after repair (m bar l/sec) |
|---------|---------------|----------------------------------|---------------------------------------------|----------------------------------|
| 1       | Joint no. – 1 | 3 x 10^(-7)                      | 2 x 10^(-4)                                | 3 x 10^(-9)                      |
| 2       | Joint no. – 2 | 3 x 10^(-2)                      | 2 x 10^(-6)                                | 5 x 10^(-9)                      |
| 3       | Joint no. – 3 | 9 x 10^(-2)                      | 1 x 10^(-5)                                | 7 x 10^(-9)                      |
| 4       | Joint no. – 4 | 9 x 10^(-7)                      | 4 x 10^(-7)                                | 8 x 10^(-9)                      |
| 5       | Valve - 6     | 3 x 10^(-7)                      | 1 x 10^(-4)                                | Not Repaired                     |
| 6       | Valve- 3      | 3 x 10^(-7)                      | 1x10^(-3)                                  | Not Repaired                     |

5. Conclusion
For good and unambiguous helium leak testing the back ground signal (BG) should ideally be kept at least ten times less than the specified acceptance limit. Normally it is desirable to maintain background of the helium leak detector as less as possible (1x10^(-9) mbar l/sec.) for better performance of the helium leak detector. However in case of maintenance of furnaces and vacuum equipment etc. it is difficult to get such a low back ground because of associated leakage from leaky joints. In modern leak detector like one used here has facility of both the gross and fine leak testing. Gross leak testing can be done just at 6 mbar vacuum and fine leak testing is possible if vacuum achieved is better than 2x10^(-2) mbar. It has been our experience that after spraying the helium gas, if leak is present meter reading will shoot up immediately which indicates clear leak signal.

Before in service helium leak testing of the furnace, it was observed that coloration of outside surface of clad tube was getting changed during trial run indicating oxidation of the surface, although dynamic vacuum of the furnace was in the range of 1x10^(-6) torr. After leak detection and corrective actions were taken significant improvement in coloration of clad tubes of fuel elements was observed, which indicates that oxidation of the tube surface has reduced considerably due to absence of air the furnace. Hence it is concluded that in service helium leak testing of vacuum furnaces helps in production of quality nuclear products as per requirement.

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