Development and Application of Radiotracer Technique for Online Leak Detection in High Pressure Heat Exchangers

H.J. Pant, V.K. Sharma, Sunil Goswami, J.S. Samantray and Gursharan Singh
Isotope Applications Division

Abstract
A radiotracer technique for online leak detection in high-pressure heat exchanger systems have been developed and successfully applied in various process industries in India. Bromine-82 as dibromobiphenyl is used as a radiotracer for leak detection in heat exchangers involving flow of organic fluids. The radiotracer is injected into high pressure side of the heat exchanger system and monitored at strategically selected locations in low pressure side using NaI(Tl) scintillation detectors connected to a preset data acquisition system. The tracer concentration curves monitored as a function of time are analyzed to identify the leaking heat exchanger(s). A number of leak detection investigations have been carried out since year 2001 leading to high economical benefits to the industry. This paper discusses principle of leak detection in high-pressure heat exchanger systems using radiotracer technique with two specific case studies.

Introduction
A leak is an undesirable interconnection between isolated parts of a system or between two systems and is suspected if there is any abnormal behavior of a system, such as loss of pressure, contamination of product or loss of process efficiency. A leak in a system can occur due to an unintended crack, corrosion or porosity, hole in an enveloping wall, loosening of bolts/joints and cracking of gaskets. After suspecting a leak(s) in a system, it is essential to confirm and identify the leaking system(s) at the earliest to avoid deterioration of product quality, loss of process efficiency, risk in safety and environmental hazards.

A heat exchanger (HX) is commonly used equipment in petroleum, petrochemical and chemical process industry. During the course of operation of these exchangers, occurrence of leakage is a common problem. Maintenance and servicing of HXs in industry is a difficult and expensive task necessitating hiring of a specialized agency. Therefore, it is necessary to confirm and identify the leaking HXs before planning shutdown and hiring a specialized agency for repair.

Online conventional analytical techniques are generally used to confirm and identify the leaking exchanger(s) provided sampling points are available at the inlets and outlets of individual heat exchangers. But a bank of heat exchangers that operate at high temperature and pressure usually do not have any sampling points at the inlet and outlet of the individual HXs because of safety reasons and thus analytical techniques cannot be applied for leak detection. There are other conventional techniques such as hydrostatic pressure test, chemical reagent test, bubble test, dye penetrant test, acoustic emission technique and helium tracer test for leak detection in industrial systems including heat exchangers. However, these techniques cannot be used online and thus require shutdown of the plant. Shutting down of the plant and applying conventional techniques is a cumbersome and time consuming procedure leading to substantial revenue loss to the industry.

Radiotracer techniques are widely used for leak detection in buried pipelines, measurement of flow parameters such as flow rates, residence time distribution, mixing/blending time in chemical reactors, sediment transport investigation in Ports,
dispersion of effluents/pollutants in coastal waters and investigation of dynamics of fluids in oil fields. Radiotracer techniques have a number of advantages (over conventional tracer techniques) such as online detection, high detection sensitivity, availability of wide range of compatible radiotracers for different phases, ease of application to different situations and often do not have any competitive alternatives. The Isotope Applications Division, BARC has developed and applied a number of radiotracer techniques in industry. Isotope Applications Division, BARC has alone carried out over 350 large-scale radiotracer investigations to benefit Indian Industry. 

At the request from different industries in India, development of online leak detection technique for HXs was undertaken by Isotope Applications Division, BARC in 2001. The technique was developed, standardized and applied in different type of HXs. This paper discusses principle of radiotracer technique with two different case studies. 

**Principle of the Radiotracer Technique**

The principle of leak detection in heat exchangers is based on differential pressure between two parts or components of the system and is shown in Fig. 1. If there occurs a leak in a heat exchanger, the fluid from high pressure side will leak into low pressure side. In shell-tube type heat exchangers in petroleum refineries, the cold feed is pumped to the tube side of the reactor and is required to be heated up before entering into the reactor, whereas the effluent from the reactor is fed through the shell-side the exchanger. The effluent flowing out of the reactor is at high temperature and transfer heat to the feed flowing through the tube side. In a feed-effluent exchanger, the feed stream (tube side) is at a high pressure than the effluent stream (shell side) and

---

**Fig. 1: Schematic diagram showing principle of radiotracer technique for online leak detection in heat exchangers**
therefore any leakage in the exchanger will be reflected in effluent side.

In radiotracer technique, a suitable radiotracer in an appropriate quantity is injected into the feed side (tube side) and monitored at the inlet and outlet of the tube side and outlet of the shell side (effluent stream) using three independent collimated scintillation detectors D1, D2 and D3, respectively as shown in Fig. 1. The tracer concentration curve recorded by detector D1, usually called as ‘injection detector’ confirms injection of radiotracer into the tube side and time of injection. The detector D2 will provide residence time distribution curve of feed in tube side. However, any leakage in the exchanger will be reflected in tracer concentration curve recorded by detector D3 mounted at shell outlet of the exchanger, usually called as ‘leak detector’. The curve recorded by detector D3 as shown in Fig. 1, has two distinct tracer peaks. First peak preceding is due to leakage in the heat exchanger and is recorded immediately after inlet tracer concentration curve as the leaked tracer bypasses the reactor. Whereas, the second peak (main peak) is due to flow of tracer through the reactor and is referred residence time distribution of the reactor. The absence of leak peak in the curve indicates no leakage in the exchanger. There is always possibility of ‘leak detector’ recording false signals other than due to leakage if not shielded properly and thus misleading the results. Therefore an additional detector D4 called as ‘brick detector’ is also mounted at the shell outlet of the exchanger that monitors background radiations and stray/false radiations other than due to leakage. The signal recorded by ‘brick detector’ avoids ambiguity in leak detection due to stray/false signal.

**Development of the Technique**

Implementation of the radiotracer technique requires selection of a compatible radiotracer for the investigation in hand, its production, packaging, transportation to the experimental site, injection into the system, detection of radiotracer at strategically selected locations and analysis of the data. Bromine-82 \(^{82}\text{Br}\) as dibromobiphenyl and as ammonium bromide is most suitable radiotracer for tracing organic and aqueous phase respectively, in leak detection investigations. The activity required varies from 40-100 mCi (1.5-3.7GBq) per test. The required radiotracers are produced in DHRUVA reactor at Trombay and transported to the experimental site in type approved lead containers / packages by Board of Radiation and Isotope Technology (BRIT), Mumbai with prior approval of Atomic Energy Regulatory Board (AERB), Mumbai. Necessary approval for conducting the investigation is obtained from the Radiation Safety Systems Division (RSSD), BARC and Atomic Energy Regulatory Board (AERB), Mumbai. At the site, the radiotracer is instantaneously injected into the system using a suitable injection system as...
shown in Fig. 2. The radiotracer is monitored at strategically selected locations using collimated scintillation detectors (size: 2 inch x 2 inch, Make: Amcrys, Ukraine) as connected to an indigenously developed multi-input data acquisition system (MIDAS). A typical collimated detector and MIDAS are shown in Fig. 3 and Fig. 4, respectively. The number of monitoring locations (detector) depends upon number of HXs in the system. Usually in a single heat exchanger, three monitoring locations (detectors) are used. The MIDAS is coupled to a computer and can be programmed to monitor tracer concentration at a preset time interval. The acquired tracer concentration data monitored as a function of time is saved and analyzed to identify the leaking HX(s).

More than eleven radiotracer investigations have been carried out successfully by Isotope Applications Division, BARC during May 2002 to November 2011 in different petroleum refineries and petro-chemical industries in India. Types of HXs for which leak-detection was taken up were shell-tube type, rod-baffle type and welded-plate type. Two case studies are discussed in detail.

Fig. 3: Collimated scintillation detector

Fig. 4: Multi-input data acquisition system (MIDAS)

Fig. 5: A typical heat exchanger system in a refinery

Fig. 6: Schematic diagram of the heat exchanger system and location of the detectors
Case Studies

**Leak detection in shell-tube type heat exchangers**

A hydrocracker plant at M/s Indian Oil Corporation, Guwahati Refinery, Guwahati, Assam is meant for conversion of fresh feed (vacuum oil gas) to diesel. The plant consists of a furnace, hydrocracker (packed bed reactor) and a high-pressure heat exchanger system consisting of a number of heat exchangers connected in series. Plant engineers suspected leakage in the heat exchanger system because of presence of high level of sulphur in the final product. A radiotracer investigation was carried out to confirm leakage and identify leaking heat exchanger(s) in the heat exchanger system. A photograph of the heat exchanger system and schematic diagram of experimental setup showing radiation detectors for tracer monitoring are shown in Fig. 5 and Fig. 6, respectively. The process and operating conditions during the tracer tests are given in Table 1. 32Br as dibromobiphenyl was used as a radiotracer. Two tests were conducted in April 2006 and about 1.85 GBq (50 mCi) activity was used in each test. The radiotracer was instantaneously injected at the suction end of the feed pump (shell side) and monitored at seven different strategically selected locations using collimated NaI(Tl) scintillation detectors (D1-D7) as shown in Fig. 3. Detector D1 (injection detector) and detector D7 record tracer concentration at the feed inlet and outlet respectively; and provide information about time of entry and exit of radiotracer from feed side of the exchanger, respectively. Leak detectors D2, D3, D4, D5 and D6 installed at tube outlets will record peaks due to leakages in the heat exchangers. In case of no leak in any of the heat exchangers, these detectors will record only the background radiation levels. Fig. 7 shows a typical tracer concentration curves recorded in one of the tests. Peaks recorded by ‘leak detectors’ (D2, D3, D4, D5, D6) indicate existence of leaks in the heat exchanger system. The leaking exchangers could be identified based on the time of appearance of the peaks. First peak recorded by detector D2 appears later than the peaks recorded by detector D3. This implies that there is no leakage in E-2C and the peak recorded by D2 is due to leakage in exchange E-2B. Similarly, the subsequent peaks recorded by detector D2 were due to leakage in other upstream exchangers. If there would have been leakage in E-2A, detector D4 would have recorded peak prior to D5 and D6. However this was not observed. This eliminates possibility of occurrence of leak in E-2B. The peaks recorded by detector D5 and D6 clearly shows occurrence of leakage in exchanger E-3B and E-3A, respectively. Subsequent peaks recorded by detector D2, D3 and D4 are due to leak in exchanger E-3B. The extent of leakage in exchanger E-2A detected by D6 was low and the same could not be reflected in subsequent detectors due to dilution of radiotracer. Thus it was concluded that exchanger E-2B, E-3A and E-3B were found to be leaking.

In order to quantify the leak rates, the area of peak recorded by inlet detector i.e. detector D1 and the area of peaks recorded by “leak detector” were compared and the leak rates were estimated using the following relation.

\[
\text{Leak rate (\%)} = \frac{\text{Area of peak}}{\text{Area of input peak}} \times 100
\]

The estimated leak rates in individual heat exchangers are given in Table 2. The total leak rate will be the...

### Table 1: Process and operating parameters in Shell-tube type heat exchangers

<table>
<thead>
<tr>
<th>Exchanger</th>
<th>Shell Side</th>
<th>Tube Side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluid</td>
<td>Temp (°C)</td>
</tr>
<tr>
<td></td>
<td>Liquid</td>
<td>Vapour</td>
</tr>
<tr>
<td>E-2A/BC</td>
<td>Feed</td>
<td>75.39</td>
</tr>
<tr>
<td>E-3A/BC</td>
<td>Feed</td>
<td>72.822</td>
</tr>
</tbody>
</table>
sum of individual leak rates. The mean total leak rate was found to be about 22.2 %. The total leak rate estimated by sulphur balance method in laboratory was found to be about 21 %.

Based on the results of the investigation carried out in April, 2006, shutdown of the plant was planned and necessary repair work was undertaken. The leakage in three exchangers was visually confirmed. After plugging the leaks, the plant was put back into normal operation. The analytical tests carried out for sulphur content in different product streams after restarting the plant showed sulphur content less than the design value (20 ppm). This indicated that the leaks in all the three heat exchangers were plugged.

**Table 2: Leak rates in heat exchangers**

<table>
<thead>
<tr>
<th>Run No</th>
<th>E-2B (%)</th>
<th>E-2A (%)</th>
<th>E-3B (%)</th>
<th>E-3A (%)</th>
<th>Total leak rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.7</td>
<td>4.7</td>
<td>7.7</td>
<td>9.4</td>
<td>25.5</td>
</tr>
<tr>
<td>2</td>
<td>7.2</td>
<td>8.6</td>
<td>6.6</td>
<td>9.0</td>
<td>31.4</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>6.7</td>
<td>7.7</td>
<td>10.4</td>
<td>29.8</td>
</tr>
<tr>
<td>Mean</td>
<td>5.3</td>
<td>6.7</td>
<td>7.3</td>
<td>9.6</td>
<td>28.9</td>
</tr>
</tbody>
</table>

**Leak detection in a welded plate type heat exchanger system**

A Diesel Hydrotreating (DHDT) unit at M/s IOCL Panipat Refinery, Panipat is designed to process a hot blend of diesel streams and to produce a diesel of a specific quality characterized by higher cetane number and low sulfur content (30 ppm wt). The unit comprises of two parallel trains, each comprising of a reactor feed/effluent exchanger, a heater, two reactors and a stripper feed preheater connected in series; and can process 50% of the total feed. The heat exchanger system in each train consists of two independent reactor feed/effluent exchangers (E1 & E2) as shown in Fig. 8. The exchangers are not of conventional shell-tube type exchangers but welded-plate type exchangers of Alfa Laval Packinox make. Each heat exchanger consists of a bundle of a number of explosion formed, corrugated, metal sheets stacked on top of each other, separated at the edges by a spacer and contained within a pressure vessel. The two fluids are distributed in the heat exchanger bundle through header boxes mounted on both sides of the exchanger and flow between the plates of the exchanger where the heat exchange takes place. The heat exchangers are mounted vertically and operate in counter-current flow mode. The hot effluent from the reactors is equally divided into two streams and fed to the effluent side of each heat exchanger. The effluent transfers heat to the feed while flowing down from top to bottom and gets cooled. Similarly, feed is pumped through a common feed line which subsequently splits into two equal streams and flows to individual exchangers. The cold feed enters the heat exchangers from bottom and flows upward as it gets heated. During the normal operation, the total flow rate of feed and effluent are about 490 tons/hr and 540 tons/hr, respectively. Whereas the pressure in feed and effluent sides are about 127 kg/cm² and 110 kg/cm², respectively. Four bellows are provided to compensate for differential thermal expansion between the hot stainless steel bundle and the pressure vessel. Since the bundle has no gaskets to soften and leak, the exchanger can be operated at temperatures as high as 550°C.

During routine laboratory analysis, the sulfur content in the product (hydrotreated diesel) was found to
be high (>200 ppm). Even on increasing the weighted average bed temperature (WABT) of the reactors, there was no reduction in sulfur content in the product, indicating that the high sulfur content is not due to reduction of catalyst activity. After eliminating all the possibilities, leakage in either or both the feed/effluent exchangers was suspected to be source of product contamination.

Since the reactor feed/effluent exchangers (E1/E2) operates at high-pressure and there were no sample points available at the inlet and outlet of both the exchangers, confirmation of leak by analytical methods was not possible. Initially a Furfural test was conducted to confirm the leakage in the system.

The Furfural tracer test confirmed the leakage in the heat exchanger system but again it was not possible to identify the leaking exchanger(s). Therefore, at the request of Indian Oil Corporation Limited, Panipat Refinery, a radiotracer investigation was carried out to identify the leaking heat exchanger(s).

In order to implement a radiotracer investigation with increased possibility of detection of even minor leaks and minimum radiation hazards, it was decided to operate the DHDT unit at about 30 % lower capacity than the normal conditions. In addition to this, the temperature of the feed was also reduced to minimize the production of vapor phase and hence enhancing possibility of detection of minor leakage(s). All the bypass and recirculation lines were also closed during the tracer test. The operating conditions during the tracer test of the heat exchanger system are given in Table 3.

The radiotracer, having activity of about 100 mCi (3.7 GBq), was instantaneously injected into the suction end of the feed pump using a specially fabricated injection system. Therefore, 50 mci (1.85 GBq) activity will be eventually injected into feed side of each exchanger. The radiotracer was monitored at seven different strategically selected locations using collimated 2 inch x 2 inch NaI(Tl) scintillation detectors. The radiotracer concentration was monitored on the common feed line, the individual feed inlets & feed outlets and the effluent outlets of the two heat exchangers (E1 & E2) as shown in Fig.8. All the detectors were connected to a computer controlled data acquisition system (DAS); set to record tracer concentration at an interval of one second. If there exit a leakage in either or both the exchangers, the differential

---

**Table 3: Actual process and operating conditions in heat exchanger system during radiotracer test**

<table>
<thead>
<tr>
<th>Exchanger</th>
<th>Feed side</th>
<th>Effluent side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluid</td>
<td>Flow rate (tons/hr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>E1</td>
<td>Reactor Feed (H₂+H₂S+H₂O)</td>
<td>183</td>
</tr>
<tr>
<td>E2</td>
<td>Reactor Feed (H₂+H₂S+H₂O)</td>
<td>181</td>
</tr>
</tbody>
</table>
Barc Newsletter

Technology Development Article

Pressure of 10 kg/cm² will cause leakage from feed to effluent side, and get detected by detector D4 and D7 mounted on counter-currently flowing effluent streams. Fig. 9 show tracer concentration curve recorded by three different detectors mounted at common feed line and effluent outlets of the two heat exchangers indicating absence of leakage in exchanger E1 and presence of leakage in exchanger E2. Thus based on the study it was concluded that out of the two exchangers, only one exchanger i.e. E2 was found to be leaking. It was not possible to quantify the leak rate because of possibility of significant loss of radiotracer due to adsorption of radiotracer within the exchangers.

Based on the results of the investigation, shutdown of the plant was planned and necessary remedial measures were initiated. During the shutdown, the leakage in exchanger E2 was confirmed and leak rate was estimated using off-line Furfural tracer test and was found to be about 3%.

Conclusions

Radiotracer technique is an ideal technique for online leak detection in high-pressure heat exchangers. The technique has been developed, standardized and successfully applied to detect leakages in different types of heat exchangers in various refineries in India. Each online leak detection investigation carried out in refineries reduces the unnecessary shutdown time by a period of 10-15 days thus leading to high economic benefits to the industry. The potential of the technique and economical benefits grown out of the applications of the technique have been recognized by Indian industry and is now being used routinely on commercial basis.

References