Optical Fibre based Distributed Sensor for Temperature Measurement

EXECUTIVE SUMMARY
At present, the temperature measurement in the sodium loops is done at a few locations using conventional sensors. It is desirable to make measurement at as many locations as possible. A Raman scattering based optical fiber sensor is developed for distributed temperature measurement. This sensor has been tested on a test loop erected for this purpose.

OUTLINE
At present, the temperature measurement in the sodium loops of breeder reactors is done at a few locations through thermo-wells and Resistance-Temperature Detectors (RTDs). It is likely that temperature variations can occur at intermediate points also. Some of these local temperature excursions may cross the safety limits, which will not be detected. It is desirable that such events be detected such that the monitoring is comprehensive and the damage, if any, can be minimized. This requires distributed temperature measurement. A programme is undertaken to study the feasibility of using optical Fibre sensor for such distributed temperature measurement.

A distributed temperature measuring system based on Raman scattering in optical fibres is developed in association with Raja Ramanna Centre for Advanced Technology (RRCAT), Indore.

In order to study the feasibility of using the fibre sensor in sodium circuits, a test loop has been designed and erected in Hall 3 (Fig. 1). The test loop is provided with automated differential heating system and equipped with conventional temperature sensors. The optical fibre sensor is carefully laid on the loop along with the conventional sensors. Measurements were made using both conventional thermocouples and Raman scattering based fibre sensor system. Optical fibre based measurements were within 5 per cent error limits of the measurements made using thermocouples. In addition, temperature could be recorded all along the pipe length (Fig.2).

The system will further be tested in the sodium test loop and later will be deployed for to the sodium circuits in reactors.

Fig. 1: Test loop for testing optical fibre based distributed temperature sensor

Fig. 2: Typical temperature profiles on the test loop obtained using optical fiber based Raman sensor
**Optical fibre based distributed sensors** have been widely used to monitor temperature. The main advantage of the system is that the fibre itself is the sensing element. Distributed temperature sensing technology shows real advantages over conventional temperature sensing technology when a temperature profile of the installation is required or when a large number of sensing points is crucial. Therefore this technology lends itself to long length applications (pipelines, tunnels, power cables, conveyor belts), applications where only small sensors can access (oil wells) and safety critical applications where it is important to have all points monitored (refineries, LNG plants, electrochemical processes).

Raman scattering based distributed temperature sensor comprises the following. A pulsed laser is injected into the optical fibre which is the sensing element. In the fibre the photons interact with the molecules of the fibre material. The spectrum of the backscattered light includes the Rayleigh, the Brillouin and the Raman backscattered light. The Raman backscattered light is caused by thermally influenced molecular vibrations. Consequently, the Raman backscattered light carries the information on the temperature of the fibre and can be used to obtain information about the temperature distribution along the fibre. The Raman backscattering light has two components: the Stokes ($I_s$) and the Anti-Stokes ($I_a$) component (Fig. 3). They can be separated from the primary and the Rayleigh backscattered light due to their differences in wavelength. The Stokes component is only weakly dependent on temperature, while the Anti-Stokes component shows a strong relation to temperature. The ratio of the intensities of Stokes and Anti-Stokes components is a measure of temperature. Since the injected light is a pulse of a few nano seconds, the time of arrival of instantaneous back scattered intensity can be correlated with the distance along the fibre length from where it is scattered.

The ratio of the intensities of the Anti-Stokes to the Stokes line shows temperature dependence and is given by

$$\frac{I_a}{I_s} = \left(\frac{n_o - n_k}{n_o - n_i}\right)^4 \exp\left(\frac{-\hbar c n_i}{kT}\right)$$

$I_a$ - intensity of Anti-Stokes-component, 
$n_o$ - light wave number, 
$h$ - Planck action quantum, 
$k$ - Boltzmann-constant 
$n_i$ - shift of light wave number 
$c$ - velocity of the light within the optical fiber 
$T$ - temperature

Optical fibre is laid on a test loop, and distributed temperature measurement is achieved using a novel method based on scattering.

**Publications arising out of this study and related work**

4. SPIE Optics East, September 9-12, 2007, Boston, U.S.A.

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