

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

COMPENDIUM OF EEMUA INFORMATION SHEETS ON TOPICS RELATED TO PRESSURE-CONTAINING EQUIPMENT

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**3rd Floor, 20 Long Lane
LONDON
EC1A 9HL**

**Telephone: 020 7796 1293
Fax: 020 7796 1294
e-mail: sales@eemua.co.uk
website: www.eemua.co.uk**



THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

The Engineering Equipment and Materials Users Association—EEMUA—was formed in 1983 by the Amalgamation of the Oil Companies Materials Association (OCMA) and the Engineering Equipment Users Association (EEUA). It is an organisation of substantial purchasers and users of engineering products, whose members include leading national and multinational companies in the petroleum, gas, chemical and energy industries, and engineering contractors that provide services to those companies. A list of Full and Associate Members (the latter being limited to membership of three technical committees) is given below. EEMUA is concerned with the design, installation, operation and maintenance of the engineering plant used by members in pursuing their business activities.

The Association aims to reduce members' costs by providing the opportunity for them to share resources and expertise in order to keep abreast of technological developments and improve the effectiveness and efficiency of their engineering activities. EEMUA supports the British Standards Institution, works with other institutions, associations, government departments, regulatory authorities and the Confederation of British Industry, and is also actively involved with other standards-making bodies, both national and international, such as the American Petroleum Institute.

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COMPENDIUM OF EEMUA INFORMATION SHEETS ON TOPICS RELATED TO
PRESSURE-CONTAINING EQUIPMENT
PUBLICATION No. 195 : 1999

AMENDMENT No.1, JANUARY 2000

Information Sheet No.11 *Policy on the Use of Bonded Asbestos and Asbestos Substitutes* is withdrawn with immediate effect.

On 24th November 1999, new regulations came into force in the UK imposing further prohibitions on the use of asbestos (SI 1999 No. 2373 *The Asbestos (Prohibitions) (Amendment) Regulations 1999*). These effectively ruled out the use of all types of asbestos except for a few, temporary derogations. The EEMUA Piping Systems Technical Committee, which is responsible for the issue and update of Pub. 195, accordingly decided to withdraw the subject Information Sheet.

EEMUA
6th January, 2000

INTRODUCTION AND SCOPE

EEMUA Information Sheets are intended for the informal, expeditious dissemination of information to Members on matters of common interest. They are primarily for guidance, and being privy to Members may contain reference to particular types of equipment and the manufacturers thereof.

The EEMUA Piping Systems Committee (PSC) has recognised for some time that the Information Sheets contain material of value to users of engineering equipment and materials other than EEMUA Members. A decision was therefore taken to compile and publish a selection of Information Sheets relating to pressure-containing equipment—to piping systems in particular. This publication is the result.

The Information Sheets contained herein are not necessarily identical with the latest 'stand alone' issues, having been edited to remove references to proprietary equipment, to effect improvements, and to correct minor errors. Where there has been significant editing, the designation '(amended)' has been added alongside the date of the current issue.

The Information Sheets were originally developed by the PSC (mainly) and INT (Inspection and NDT Technology) Committees from Member Companies' collective experience and practices.

Each Information Sheet is self-contained, with its own list of references (or else references are given in full in the text).

Note on Amendment No. 1

Information Sheet No. 11 *Policy on the Use of Bonded Asbestos and Asbestos Substitutes* was withdrawn on 6th January 2000. Accordingly the Information Sheet has been deleted from this publication.

On 24th November 1999, new regulations came into force in the UK imposing further prohibitions on the use of asbestos (SI 1999 No. 2373 *The Asbestos (Prohibitions) (Amendment) Regulations 1999*). These effectively ruled out the use of all types of asbestos except for a few, temporary derogations. The EEMUA Piping Systems Technical Committee, which is responsible for the issue and update of both Information Sheet No. 11 and the present publication, accordingly decided to withdraw the Information Sheet.

Units

Units used are metric, primarily SI. 'Bar' means gauge pressure.

INFORMATION SHEET No 8, November 1996 (amended)

DETECTION AND EVALUATION OF IN-SERVICE DETERIORATION IN PIPES AND TUBING (INCLUDING IN-SITU WALL THICKNESS MEASUREMENT)

(FORMERLY TITLED 'THICKNESS AND CORROSION MEASUREMENT OF PIPES
AND TUBING IN SITU')

1 INTRODUCTION AND SCOPE

This Information Sheet describes equipment used by EEMUA Member Companies, and the experience gained thereby, for detecting and evaluating in-service deterioration from corrosion or wear in the following applications:

- heat exchanger tubing
- pipes which are accessible from the outside
- detection of corrosion under insulation.

It is not an exhaustive survey of all available equipment. The field is one of rapid change and development, and hence any review of this type will soon become out-of-date.

Comments and information on experiences of other member companies with the equipment described and also with other similar equipment would be welcome for inclusion in any future update of this review.

2 INSPECTION OF HEAT EXCHANGER TUBING

2.1 General

For the inspection of heat exchanger tubing, the choice of a particular technique will be determined by:

- type and location of expected defects in the heat exchanger tubing under investigation
e.g.
 - general corrosion, pitting corrosion, crack-like defects, etc.
 - at the end of the tubing, inside, outside, etc.
- accessibility of the tubes, which will be dependent on the type of heat exchanger, e.g. air cooler, shell-and-tube type, U-tubes, etc.
- the material properties of the tubing, e.g. ferromagnetic or non-ferromagnetic
- the cleanliness of the inside of the tubes, which will be dependent on the medium flowing through the tubes during operation and the applied cleaning technique (if any) during the shutdown.

The extent of inspection can vary from 100% internal examination of all tubes and 100% examination of all accessible external surfaces to examination of selected, critical locations. Examples of the latter are: visual examination of tube ends for erosion/corrosion; probing suspect internal surfaces for pits; removal of sample tubes for destructive testing; and close visual examination for mechanical damage at accessible baffle areas.

The techniques that are currently known to be available are described below, and summarised in the Table at the end of this Information Sheet.

2.2 Visual Inspection

The tube internal wall can be inspected by means of an endoscope or a small silicon chip-based TV camera. In practice these can only be used to inspect small numbers of tubes due to the slowness of the inspection process. Quantification of defects is very difficult as depth cannot be evaluated in a reliable way from a two-dimensional picture. Corrosion in the outer parts of the tubing can be quantified using mechanical feelers.

For internal tube inspection with modern silicon chip-based TV cameras, it is now possible to quantify the depths of defects using a PC-based system with appropriate software.

2.3 Radiography

Radiography can be applied to determine the wall thickness profile of the exposed sides of some of the outer layers of tubing. The technique is of course restricted to exchangers where the tubes are accessible from the outside. Inspection is slow and localised, but the technique can be effective for spot checks and verification of other techniques. Where access permits, panoramic exposure with a gamma-ray source inside the tube and film on the outside can be applied. However panoramic exposure cannot be used to provide a wall thickness profile and therefore only has limited use in identifying areas for further investigation by other techniques.

2.4 Acoustic Reflectometry (Acoustic Ranger)

The principles of the acoustic reflectometry technique are similar to sonar or radar techniques, viz. an acoustic pulse with a fixed frequency is excited by a loudspeaker system and propagates through the air inside the heat exchanger tube. Due to leaks, debris, weld-penetration, changes in tube sizes and/or blockages, part of the incident acoustic pulse is reflected resulting in echoes which can be picked up by a microphone positioned near the loudspeaker. The echo pattern is displayed on an oscilloscope, and since the velocity of sound in air can be accurately computed for the particular ambient conditions, the location of the defect can be determined. Quantification of corrosion pits is not possible using this technique.

As far as is known at the time of writing, the Acoustic Ranger, manufactured by Industrial Electronic Services, London is the only equipment on the market that employs this principle. (*Note.— Reference to the Acoustic Ranger does not imply a recommendation by EEMUA to use this equipment in preference to other makes employing the principle of acoustic reflectometry that may come on the market.*) According to the manufacturers, a hole of ½ mm diameter can be detected at a distance of 30 m in a 25 mm diameter tube, and for an obstruction inside the pipe a change of about 5% in cross-sectional area can be detected at a distance of 20 m in a 40 mm diameter tube. Inspection speeds of 500 tubes/hour are claimed by the manufacturer.

PC-based systems are now available. Although a high level of operator skill is still required to interpret the results, interpretation is not as difficult as with the oscilloscope display.

2.5 Ultrasonic Inspection

An immersion, pulse echo technique is used to measure wall thickness. The ultrasonic transducer is contained in a test head which fits into and is centred in the heat exchanger tube. The ultrasonic pulses are emitted along a path parallel to the tube axis. These pulses are then reflected by a 45° mirror so that they are directed radially into the tube wall. As the mirror rotates, the ultrasonic beam traverses around the tube circumference. Reflections from the inner and outer walls follow the same path back to the transducer. The time interval between the interface echo (the first reflection from the inner wall) and the backwall echo (the first reflection from the outer wall) gives the measure of wall thickness.

When the probe is advanced along the tube, the ultrasonic pulses trace out a helical path on the tube wall. If the advance rate is not more than 4 cm/s, the separate turns of helical path are contiguous and no area of the tube is missed. By moving the probe from one end of the tube to the other, the complete tube can be inspected.

The ultrasonic technique can be used to quantify pitting corrosion, but requires good cleanliness of the internal bore. A disadvantage of the application of the technique as currently practised is the requirement that an operator watch an oscilloscope screen for the occurrence of deviations in the detected signals. Once such a deviation has been detected, a hard copy is obtainable from the storage oscilloscope screen by Polaroid photography.

The inspection rate for such a technique based on a contiguous helical path of the acoustic beam can be up to 2.4 m/min. However in practice the rate is reduced as the operator watching the screen has to evaluate the tube condition. In cases where the tubing contains only a few indications, a rate of 4 to 6 tubes per hour is typical, but the rate can drop to 4 to 6 tubes per day where there are lots of indications. No hard copy inspection record is obtained, except for selected locations where the operator may decide to make a photograph of the oscilloscope screen.

Computerised and digital systems are now available.

2.6 Eddy Current Inspection

2.6.1 Non-ferromagnetic Tubes

The eddy current inspection system consists of an internal probe connected to an eddy current instrument. The probe can be pulled from the far end of the tube to the tubesheet, either manually or by means of a probe puller. As the probe traverses the inside of the tube, changes in the electromagnetic field caused by differences of the electrical conductivity, the magnetic permeability, the geometry and the presence of defects in the tubing are monitored. These changes are displayed on a cathode ray tube and a strip chart or tape recorder.

In order to be able to inspect tubes for both internal and external defects, the penetration depth of the eddy currents should be approximately 1.3 times the wall thickness. The penetration depth can be adjusted by means of the test frequency. A practical method for selection of the test frequency is the use of a calibration tube with internal and external defects, as described in ASME Sec. V (*Nondestructive Examination*), Article 8, Appendix I. In cases where the frequency is properly selected, internal defects can be distinguished from external defects by analysis of the impedance diagram.

However an unambiguous depth evaluation of a defect cannot be obtained measuring only the phase or amplitude of the signal. For proper depth evaluation a defect has first to be classified as to its defect type, followed by depth quantification. This classification can be based on pattern recognition. For a particular class of defect similar eddy current signal patterns are expected, and in some more advanced systems a microcomputer is used for this pattern recognition. However, in cases where more than one eddy current signal occurs simultaneously, this pattern recognition might fail. By application of a multi-frequency approach the unwanted, disturbing eddy current signal, e.g. from a tube support, can be suppressed.

2.6.2 Ferromagnetic Tubes

Ferromagnetic tubes are much more difficult to inspect by means of eddy current techniques because of the high magnetic permeability. This necessitates the use of low measurement frequencies to enable the electromagnetic waves to penetrate the tubing undergoing inspection.

Unfortunately, the use of low measurement frequencies reduces the sensitivity of the system. Furthermore, local variations in the permeability (e.g. due to hard spots) complicate the interpretation of the results of the eddy current inspection. Some commercially available systems reduce the relative permeability of ferromagnetic tubes by partial magnetic saturation of the tube at the location undergoing inspection. However, application is cumbersome due to the high magnetic drag.

In general application of eddy current techniques, inspection can be done at a high speed being mainly limited by the mechanical transport system of the probe. The tubes need to be cleaned prior to inspection, but to a lesser extent than for the other techniques provided the layers of dirt, scale, etc. are non-magnetic and non-conductive.

3 THICKNESS MEASUREMENT OF PIPES FROM THE OUTSIDE

Wall thickness measurement of pipes which are accessible from the outside can best be done using an ultrasonic technique. For a review of available ultrasonic instruments for wall thickness measurements the reader is referred to Information Sheet N° 7: *Ultrasonic Inspection—Data Recording and Display Systems*, Thickness Measurement.*

The information that follows is additional to that found in the above reference.

Various wall thickness measurement instruments (digital direct reading, screen image, etc.) with various probe types can be used on corroded specimens. In a number of test experiments it was found that the variation in the standard deviation of the measurement error (the precision) ranged between 0.22 mm and 1.23 mm. A test with different operators using the same equipment and the same procedure showed a variation in wall thickness readings between 0.13 mm and 0.51 mm (one standard deviation). The influence of the operator, equipment and procedure on painted plates (measurement from the painted surface with corrosion on the opposite side) was also investigated. A reproducibility of ± 0.8 mm (two standard deviations) was found in the results averaged over all operators in cases where the operators used their own procedure and equipment. With standardised procedure and equipment a reproducibility of ± 0.22 mm can be achieved.

* Available to EEMUA members only.

4 DETECTION OF CORROSION UNDER INSULATION

4.1 Flash Radiography

To reveal external gross corrosion of insulated process piping without the need to remove the insulation, flash radiography can be applied. This technique is fast in comparison with conventional radiography because of the short exposure time (approximately 50 nanoseconds), relatively low radiation hazard, and portability of the equipment. An additional advantage of the technique is that suspect locations can be regularly inspected on-stream, besides or instead of inspection of the complete pipe during a shutdown and after dismantling. The application of flash radiography sometimes makes dismantling superfluous so that a higher quality, more watertight insulation becomes economically attractive.

The radiation is generated by a battery powered portable X-ray set giving one or more pulses of radiation. The number of pulses can easily be adjusted, and determine the intensity of the radiation.

To reveal corrosion under the insulation, a tangential exposure is made using the described source in combination with a very fast, low resolution film. The contour of the outer pipe reveals the presence of corrosion products, as the densities of insulation material and oxides are significantly different.

In view of the short duration of the pulse and the low weight of the X-ray set, exposures are mainly made with the set hand-held. Depending on the situation a tripod can also be used.

The presence of external (gross) corrosion products which have a larger volume than the original material will lead to an irregularly shaped contour. Also, the presence of water in the insulation material will be clearly visible on the image. The length of section that can be covered in one exposure is approximately 40 cm at a film focus distance of approximately 70 cm.

The image is recorded on very fast medical or Polaroid film in combination with an appropriate fluorescent amplification screen. The results are satisfactory considering that speed is more important than detail of image. For inspection of horizontal parts, the cassette can be quickly installed on the pipe by means of adhesive tape or hand-held rope. For inspection of bends and vertical pipes special clamps are made, but often rope or rubber bands will be sufficient. On average some 60 exposures a day can be made depending on the accessibility of the piping.

4.2 New Techniques

A number of new techniques for assessing the condition of pipework under insulation are currently being investigated. Of these the eddy current systems seem to be the most promising. At least one contractor offers a low frequency eddy current system, however one of its limitations is that it cannot be used to inspect facilities with galvanised weather covering. Another contractor is developing a pulsed eddy current system which will permit inspection through galvanised weather covering.

Table: Methods for Inspection of Heat Exchanger Tubing

Methods	Comment
1. Localised inspection a) Visual inspection • endoscopes • video camera b) Radiography	Can be used for a qualitative assessment of the internal condition of the tubing. Hard copy can be obtained by photographs or video record. Thorough cleaning of tubes required. Can be used to evaluate the side wall corrosion of tubes in the outer layers of the bundle that are accessible, e.g. the top and bottom rows of an air cooler. No cleaning required.
2. Inspection of selected tubes— Ultrasound	Can be used for wall thickness evaluation along both length and circumference of the tubing. The technique requires a high degree of cleanliness of the tubes. Inspection speeds depend on the number of indications found and range from 4-6 tubes/hour to 4-6 tubes/day. Hard copy at location selected by the operator is in the form of photographs of the oscilloscope screen.
3. 100% inspection a) Eddy currents b) Acoustic Reflectometry (Acoustic Ranger)	Can be used to evaluate both internal and external condition in case of non-ferromagnetic tubing. For ferromagnetic tubing, only the internal condition can be assessed. Some fouling in the tube is acceptable, provided this is non-magnetic. The inspection speed can be up to several metres per second, depending on the mechanical transport mechanism. Normally all data is collected on a tape and/or paper recorder. Can be used for detection of leaks and obstructions in the tubing. The inspection speed can be very high, up to 500 tubes per hour, but no hard copy is obtained. Fouling can cause signal disturbance and might obscure leaks.

INFORMATION SHEET No 14, Rev 1, September 1998

THERMAL IMAGING**1 INTRODUCTION**

The ability to measure surface temperature of on-stream plant and equipment in the process and power industries is a key feature for ensuring safe, reliable operation and energy conservation. Typical examples of equipment suited to such temperature investigation include cold wall reactors, electrical equipment and furnace tubes. Among the methods available for temperature measurement are:

- permanent thermocouples
- pyrometry
- contact thermometers
- temperature sensitive paints
- temperature sensitive crayons.

All of the above methods have proven good performance records for particular situations. Current thermal imaging systems are now so well developed that they can replace all the above methods, with the exception of thermocouples. Thermocouples are particularly useful when monitoring plant items that are not in line of sight, which is a prerequisite of thermal imaging.

Thermal imaging has now been developed to the extent that it provides process equipment owners with a capability to perform predictive maintenance and assess condition non-intrusively. This information sheet outlines the systems available and gives examples of typical applications.

2 BACKGROUND

The ability to produce images of objects from the infra-red radiation (heat) emitted by them became commercially viable in the 1960s. Early equipment utilised a liquid-nitrogen cooled detector to convert the infra-red radiation into electronic video signals. As such the equipment was bulky, required a 110 V supply and was not easily portable for site survey work. Developments through the 1970s focused on improved portability through the use of battery power, although the liquid nitrogen cooling remained. A technical breakthrough in the 1980s introduced a thermo-electrically cooled detector, and led to more portable and useful imagers for site applications. Since then further improvements have been made including the use of a miniature Stirling cycle cooler and the very latest detectors which require no cooling.

In parallel with the improvements in the detectors, there has been a move from analogue to digital signal processing. This has been made possible by the reduction of computer processor and memory costs. Current systems are able to digitise images captured by the detector and store for future processing and eventual reporting.

3 CURRENT SYSTEMS

Equipment currently available falls broadly into two categories:

- simple hand-held imagers which are particularly easy to use for preventative maintenance tasks
- multi-function systems capable of digitising/ storing both images and sound (permitting recorded commentary) for comprehensive post-measurement processing and reporting.

The images shown on the last page were obtained with equipment in the second category.

4 EMISSIVITY

A key parameter in obtaining absolute temperature readings with any instrument surveying infra-red radiation is the thermal emissivity of the object. In order to compute temperature accurately, emissivity needs to be obtained from published literature and the appropriate value input either via the thermal imaging camera menu or later when the data is being processed by computer. If the absolute temperature value is required, experimental correlation may be undertaken to improve accuracy.

5 TRAINING

Modern systems are fairly straightforward to use, but it is essential that operators undergo training with the equipment manufacturer to understand fully the underlying principles and limitations of the method.

6 APPLICATIONS

The speed of data capture enables a large quantity of information to be obtained on a single visit to a plant. Typical applications are listed below, with specific examples, italicised in brackets, illustrated by the corresponding images on the last page.

- **Refractory/ insulation:** breakdown of refractory linings/ coatings; monitoring drying out of refractory; blockages in insulated/ refractory lined pipe (e.g. cold spots in otherwise hot piping). (*Furnace casing, stack, refractory-lined reactor vessel.*)
- **Mechanical:** furnace tube temperatures in regions remote from installed thermocouples; condition of shaft bearings. (*Furnace tubes, pump motor.*)
- **Electrical:** condition assessment of overhead lines, contacts, transformers. (*Transformer.*)
- **Energy conservation:** building heat loss surveys. (*Building.*)
- **Steam systems:** identification of defective traps, leaks under insulation. (*Steam tracing/ traps.*)
- **Miscellaneous investigations:** tank levels, sludge build up in line, heat exchanger performance, safety/ block valve let by. (*Partially blocked line, airfin exchanger.*)

The ease of use of the system means that many novel future applications can be envisaged, particularly where equipment condition can be inferred from temperature data. Descriptions of such applications and comments on thermal imaging systems by users will be very welcome for possible inclusion in any future update of this information sheet.