DEVELOPMENT OF NONDESTRUCTIVE EVALUATION METHODS FOR COAL-CONVERSION SYSTEMS

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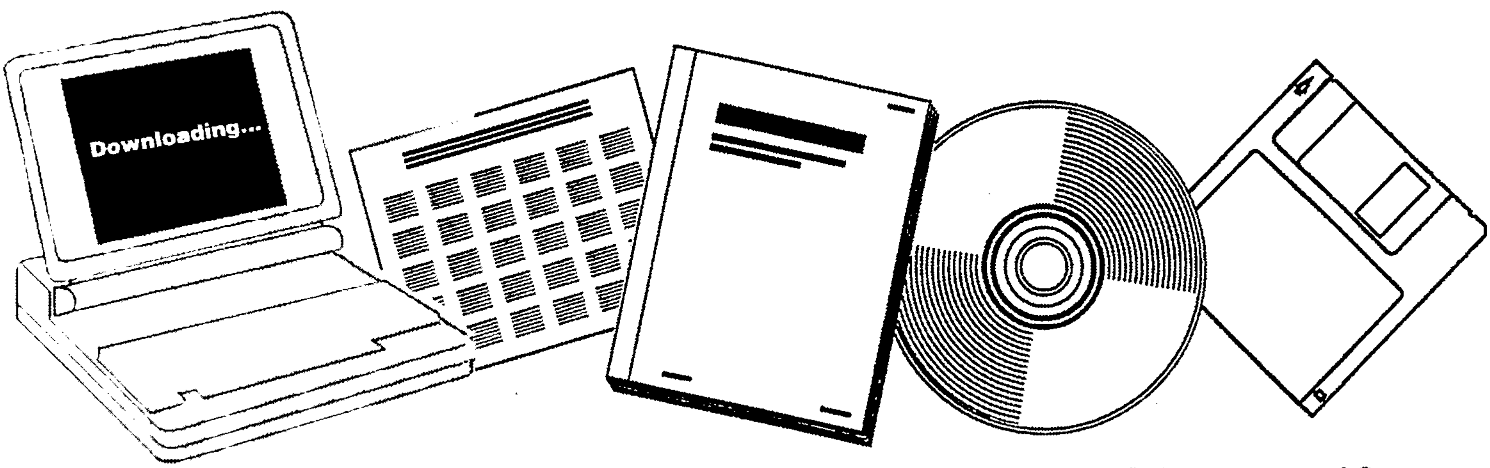

DEVELOPMENT OF NONDESTRUCTIVE EVALUATION METHODS FOR COAL-CONVERSION SYSTEMS

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DEVELOPMENT OF NONDESTRUCTIVE EVALUATION METHODS FOR COAL-CONVERSION SYSTEMS*

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Abstract: Coal-conversion processes require the handling and containment of high pressure, high temperature, corrosive and erosive gases and liquids often containing particulate loadings. These severe environments cause materials failures that reduce successful and long-time operation of coal-conversion systems. The determination of the material and component response and development calls for proper nondestructive examination methods, equipment, and techniques. This paper briefly describes the nondestructive development efforts in high-temperature, wall-thickness measurements for in situ erosion data, passive infrared imaging applications for thermal profiles, gamma radiographic applications for crack and erosion detection and acoustic methods for failure prediction.

Key words: Nondestructive evaluation; coal gasification; ultrasonic inspection; infrared imaging; refractory liners.

Nondestructive evaluation (NDE) methods for coal-conversion systems must of necessity encompass a broad spectrum of applicable technology. Transfer lines, for example, may be refractory lined or unlined, depending upon the requirements of the location, i.e., composition, temperature, and pressure of the flow. Preoperational inspection and on-line monitoring systems that measure the material response of materials systems require different nondestructive examination approaches. In nonrefractory-lined transfer lines, ultrasonic pulse-echo systems can be developed to measure wall thinning caused by erosion/corrosion at high temperature. However, the porosity of a refractory, acoustic impedance of a refractory/steel interface, and poor acoustic transfer properties do not allow ultrasonic pulse-echo methods to be used on refractory-lined components typical of coal-conversion process systems. Gamma radiography or passive infrared imaging with appropriate thermal models is necessary to determine the material response and/or structural integrity of refractory-layered structures. In addition, some components such as the lock-hopper or pressure let-down valves have a high initial cost and are time consuming to replace. Nondestructive evaluation methods to assist in determining the optimum time for replacement of such components are of value. The broad-based ERDA/FE sponsored nondestructive evaluation development program at Argonne National Laboratory is designed to address the above areas.

The ultrasonic monitoring of the erosion of high-temperature steel transfer lines requires a waveguide design that must consider: (a) signal-to-noise ratio, (b) energy transfer, (c) material attenuation, (d) appropriate interface geometry (including attachment mechanism), and (e) a satisfactory cooling mechanism. These considerations have led to a delay-line design that will shortly be employed on several coal-conversion pilot plants. A schematic of the delay-line design and associated temperature decay curve is shown in Fig. 1. Ultrasonic thickness measurements require a reflection at the inner and outer wall surfaces to determine the time of flight of the pulse and hence the wall thickness. A typical amplitude decay of the back-wall reflection is shown in Fig. 2. This is a critical reflection because part of the ultrasonic system is triggered by the back-wall amplitude, and an unsatisfactory amplitude would cause the system to fail.

A complete material wall-thickness measurement system using this delay-line design is being implemented to monitor real-time erosion of the main coal feed line of the Synthane coal-gasification plant. Figure 3 shows the coal feed elbow and array of 31 transducers that will be used to establish real-time erosion. A large number of transducers are required on this initial system for a complete mapping of the erosion pattern on this critical component. Clearly, such a large number of transducer sites is not required in all applications, and methods have been developed that will allow the ultrasonic delay line to be attached to existing piping for in-place monitoring.

Gamma radiography has been shown to be capable of clearly visualizing the bore of refractory-lined transfer lines. Figure 4 shows a double-wall gamma radiograph taken with ^{60}Cobalt and Eastman Kodak Type AA film. The dark bore region is sharp, and thus time sequential images could be used for erosion-rate measurements. Figure 5 is a schematic diagram of the transfer line showing the refractory thickness and bore diameter for the double-wall radiograph. The refractory in this case is KAOTAB, which is a high-density cast-alumina refractory with a density of $\sim$150 lb/ft^3.

The high temperatures and high pressures of most gasification systems have also demanded the use of refractory-lined pressure vessels. The most common methods used to install refractories are gunning or casting. The protective refractory lining is usually monolithic or layered with low-density insulation covered by a high-density hot face. These refractory-steel structures are used with or without water-cooling jackets. Schematic diagrams of typical dry-wall and water-cooled wall pressure vessel sections are shown in Figs. 6 and 7.

Thermal cycling and the resultant moisture condensation during start-up and shutdown can cause degradation and cracking of the refractory. This can result in sufficient refractory spalling to expose so that the steel shell would be exposed to high temperature and pressure. The thickness of the installed refractory and the uniformity of the refractory density is important for long duration runs. Gamma radiography has been shown to be a viable method to not only locate cracks but also to map refractory thickness variations. Figure 8 is a plot of normalized radiographic film density as a function of refractory thickness for KAOTAB refractory (of uniform density) on a 3/4-in. steel plate. The data were normalized by means of a steel step wedge and the characteristic amplitude transmission-exposure (t-E) curve for Eastman Kodak AA radiography film (see insert on Fig. 8). In the linear range of the t-E curve, the density D can be related to the exposure E as follows:

$$D = \gamma_n \log E - D_o, \tag{1}$$

where

D = photographic film density,

γ_n = slope of line curve,

E = exposure = IT,

I = intensity,

and

T = time of the exposure.

The results of the photographic density versus refractory thickness were verified by a field application on the Battelle-Columbus coal-gasification process development plant.

Additional work is being conducted on the use of remote thermal-sensing and pattern-recognition techniques through the use of passive infrared imaging systems to obtain thermal profiles on critical components. Expansion bellows, necessary in long, high-temperature transfer lines, are in dynamic states of design, and full field thermal mapping is useful in determining design effectiveness, i.e., indicate particulate buildup, erosion, or gas by-pass flows. Figure 9 shows the general exterior geometry of an expansion bellows and a typical real-time isothermographic image. Such images are being obtained by the use of a commercially available AGA Model 750 portable infrared scanning camera that produces a complete image in 40 ms. The use of pattern-recognition methods by means of digital computers will be employed to compare the thermal patterns generated by particle erosion.

Other work is also being conducted on acoustic emission as a means of detecting crack initiation and propagation in refractory-layered vessels.

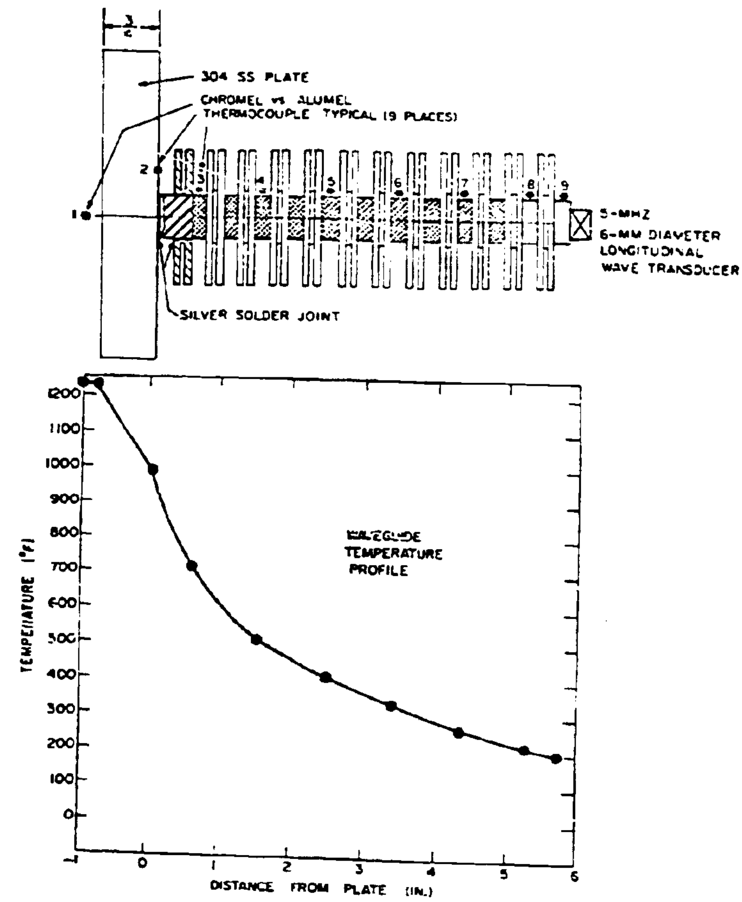

Fig. 1. Air-cooled Waveguide and Temperature Decay Curve with Block Diagram of Instrumentation. Neg. No. MSD-62454.

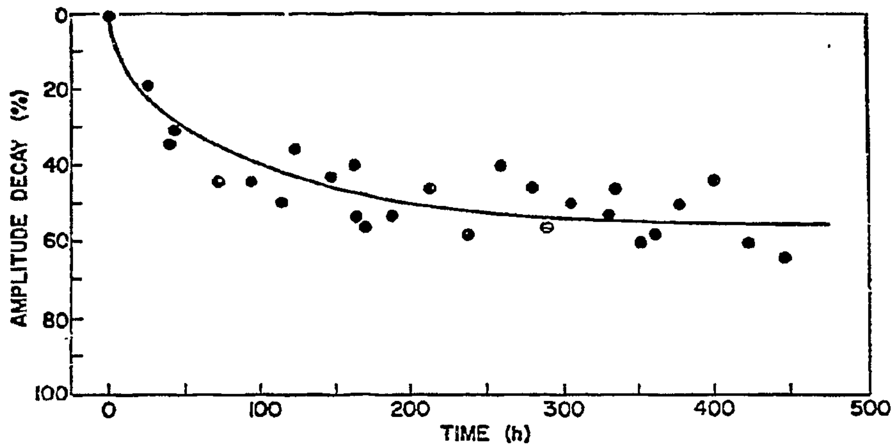

Fig. 2. High-temperature Ultrasonic Backwall Signal Amplitude Decay Curve. Neg. No. MSD-62431.

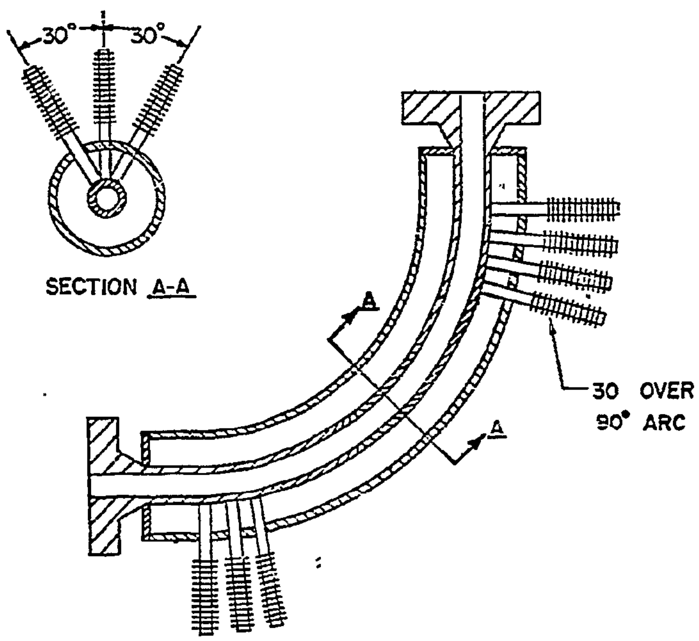

Fig. 3. Line Drawing of Coal Feel-line Replica. Waveguides are axially staggered ±30° to cover a 60° cross-sectional sector. Neg. No. MSD-62551.

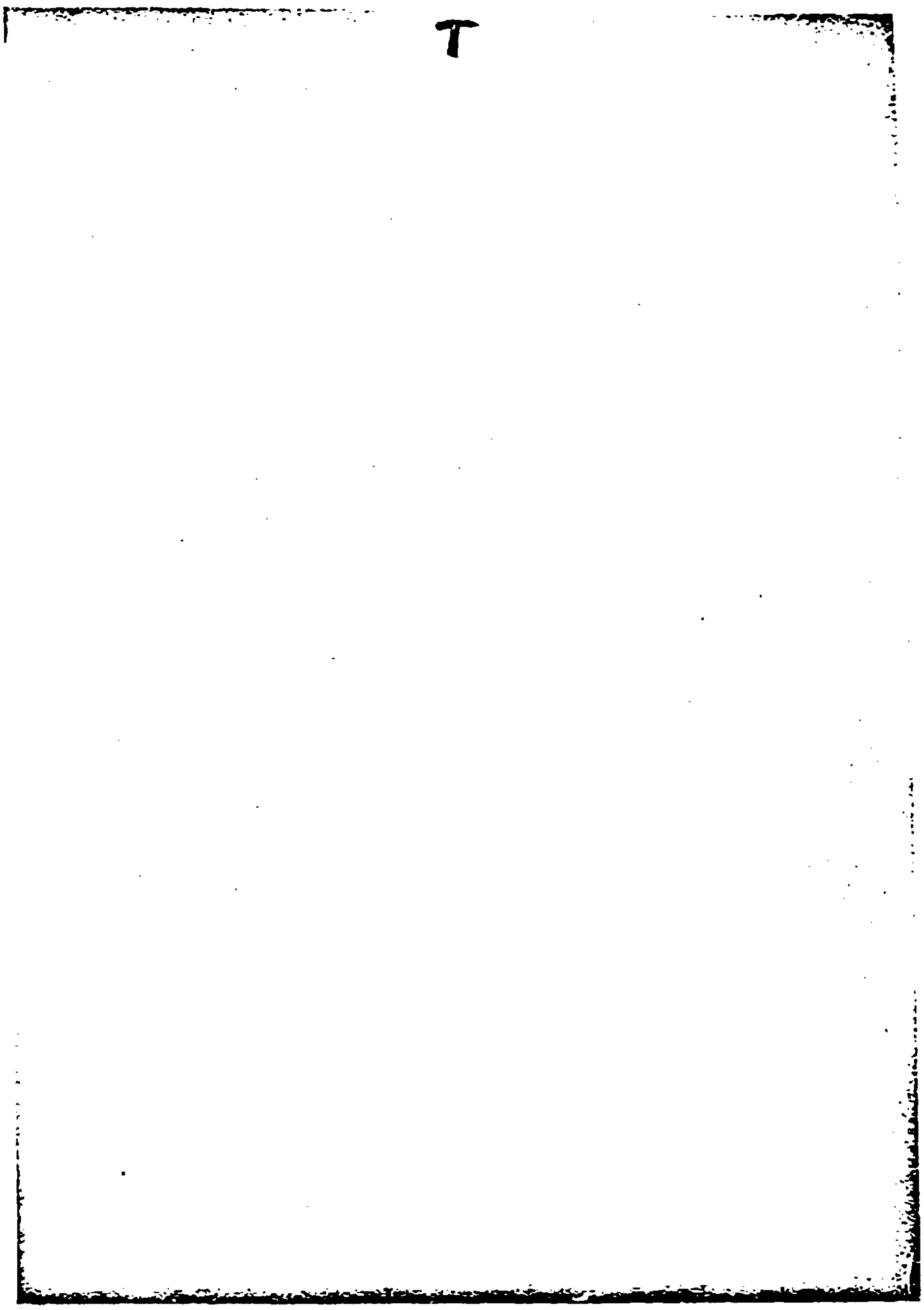

Fig. 4. Typical Gamma Radiography Taken of Refractory-lined Transfer Line. Neg. No. MSD-62811.

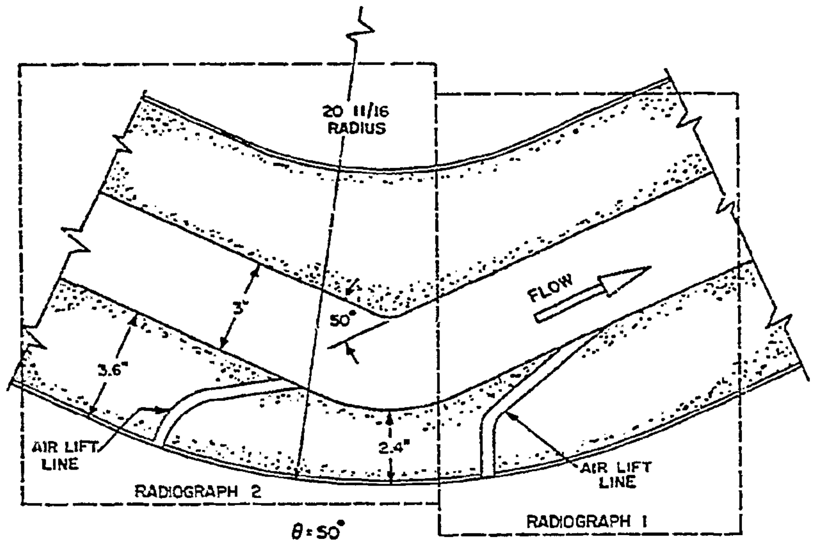

Fig. 5. Schematic Diagram Showing Refractory Thickness for Double-wall Radiograph. Neg. No. MSD-62805.

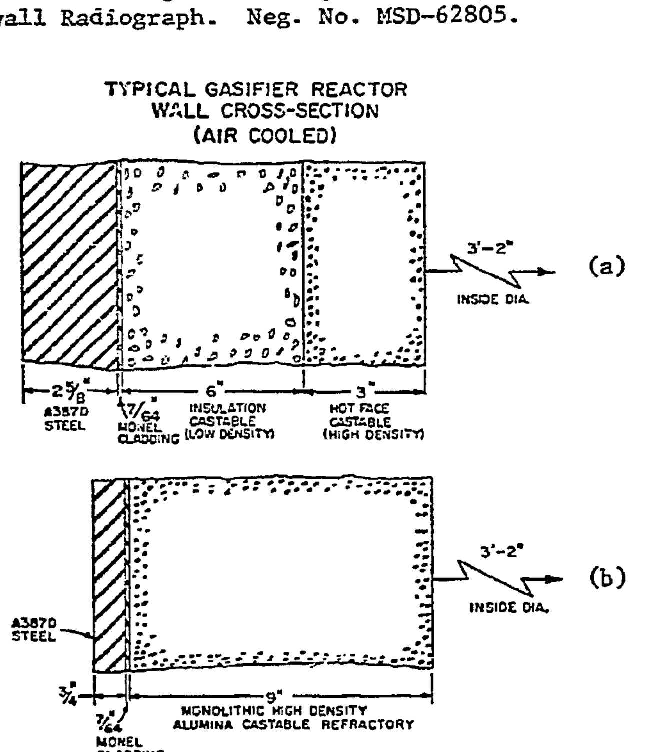

Fig. 6. Schematic Diagrams of Typical Dry-wall (Air Cooled) Refractory-lined Pressure Vessels. (a) Two-component refractory and (b) monolithic refractory. Neg. No. MSD-62807

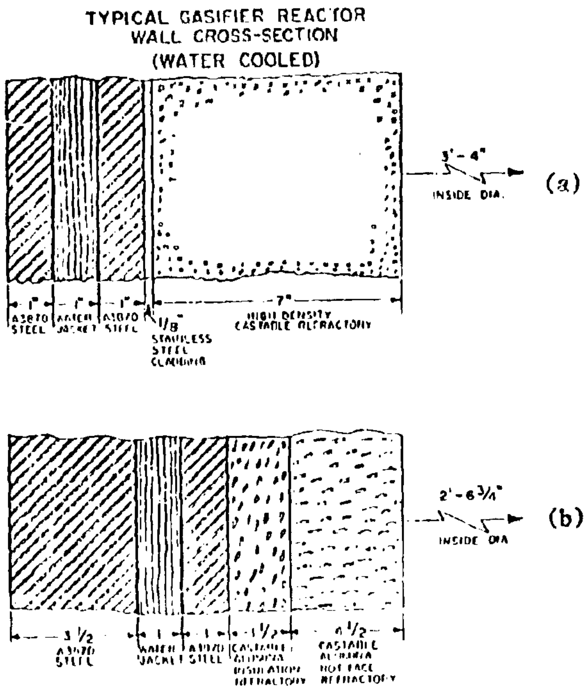

Fig. 7. Schematic Diagrams of Typical Water-cooled Refractory-lined Pressure Vessels. (a) Monolithic refractory and (b) two-component refractory. Neg. No. MSD-62806.

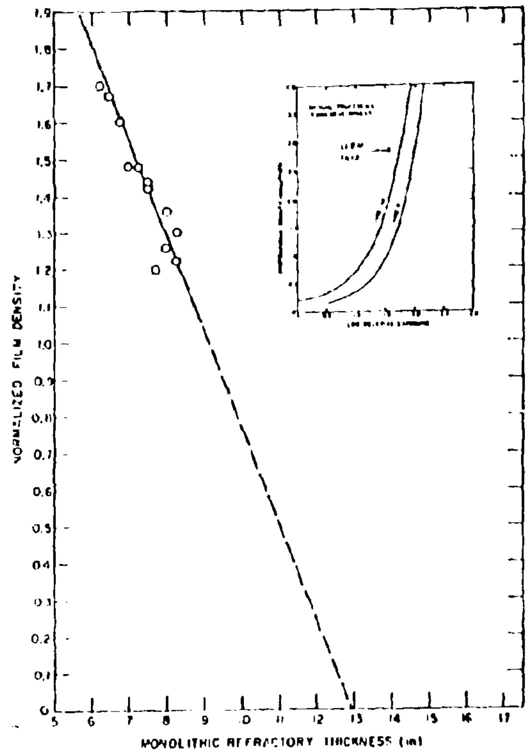

Fig. 8. Normalized Radiographic Film Density as a Function of Monolithic Refractory Thickness on a 3/4-in. Steel Plate. Neg. No. MSD-62808.

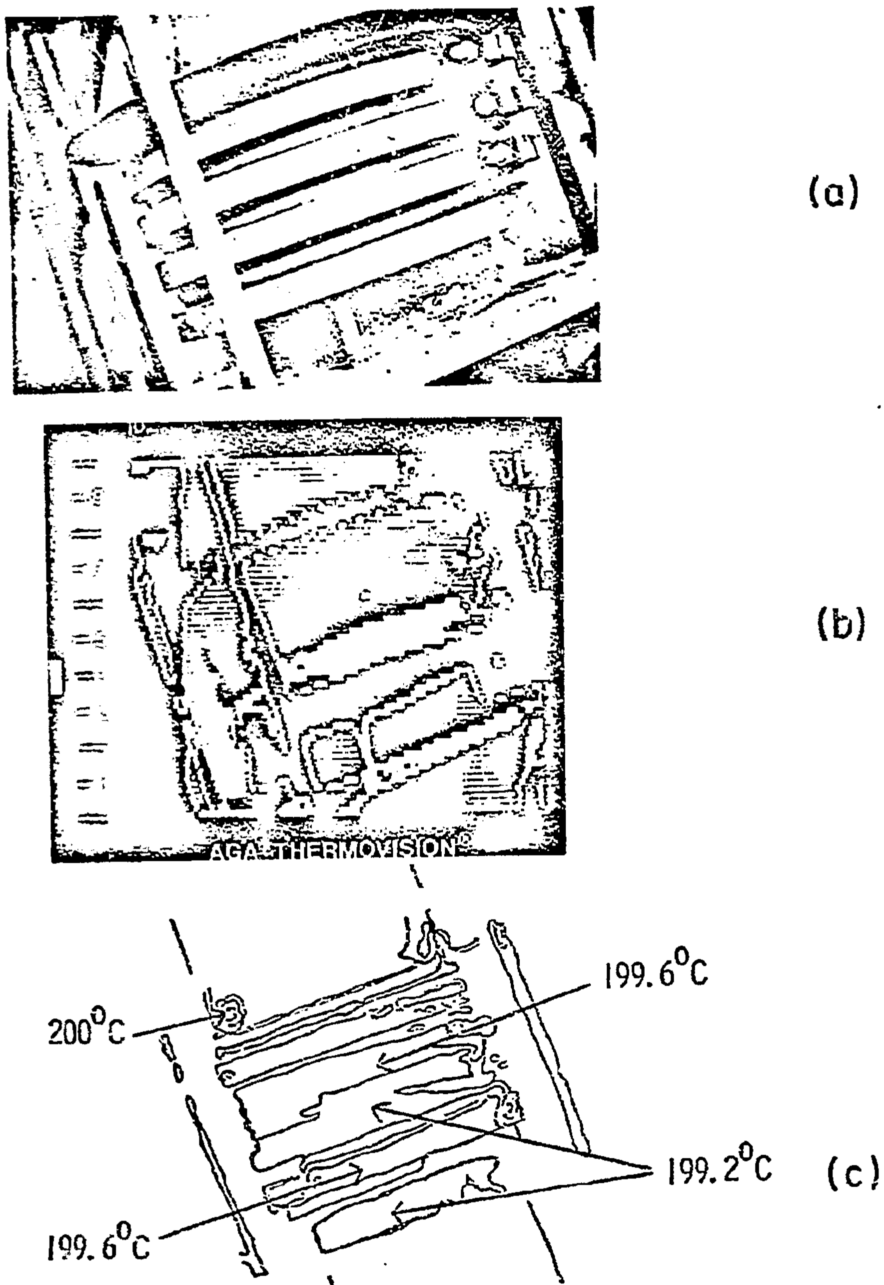

Fig. 9. Infrared Thermal Profiling of Bellows Expansion Joint of Bellows Expansion Joint of CO_2 Acceptor Coal-gasification Pilot Plant. (a) Conventional photo of bellows expansion joint, (b) isothermogram image of bellows expansion joint, level at 199°C, and (c) composite thermal profile map of expansion joint. Neg. No. MSD-62809.

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