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THE MEASUREMENT OF RADIANT HEAT FLUX IN LARGE BOILER FURNACES—II. DEVELOPMENT OF FLUX MEASURING INSTRUMENTS

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Abstract — To meet power station requirements, two permanently installed instruments have been developed for measuring the heat flux absorbed by the boiler tubes and a portable instrument developed for measuring the incident radiation from the flames. The thermal performance of each instrument has been thoroughly investigated using computer models. Extended trials of the three instruments have been completed which indicate that they can provide accurate and reliable methods for measuring heat flux in boiler furnaces.

NOMENCLATURE

- a, length of instrument measuring cylinder;
- e, emissivity of boiler tube surface;
- h_s, heat-transfer coefficient on boiler tube inside surface;
- k_m, thermal conductivity of instrument measuring cylinder material;
- k_t, thermal conductivity of boiler tube material;
- Nu, Nusselt number;
- P, steam pressure;
- Pr, Prandtl number;
- q, heat flux per unit surface area;
- Q, radial heat flow per unit length of boiler tube;
- r_i, inside radius of boiler tube;
- r_o, outside radius of boiler tube;
- Re, Reynolds number;
- T_{bi}, temperature of inner surface of boiler tube;
- T_{bo}, temperature of outer surface of boiler tube;
- T_f, equivalent black body flame temperature;
- T_i, temperature of instrument measuring cylinder lower thermocouple;
- T_o, temperature of instrument measuring cylinder upper thermocouple;
- T_{mi}, temperature of instrument measuring cylinder base;
- T_{mo}, temperature of instrument measuring cylinder surface;
- T_s, saturation temperature;
- x, distance between measuring cylinder thermocouples;
- y, distance between measuring cylinder lower thermocouple and outside surface of boiler tube.

Greek symbol

- σ, Stefan–Boltzmann constant.

1. INTRODUCTION

THE FIRST part of this paper has outlined the continuing need for measurements of heat flux in boiler furnaces. It has shown that the accurate measurement of heat flux in a furnace environment is extremely difficult. Fortunately, an accuracy of $\pm 15\%$ is sufficient for most purposes. In the highest flux regions of furnaces where these measurements are normally required, the radiation component of heat flux is in excess of 95 % of the total, so that the small convective component can be excluded from any design considerations of flux measuring devices.

High duty fossil-fuelled power station boilers currently operate at heat fluxes up to 600 kW m^{-2} whilst those at present under construction will be operating with peak fluxes in excess of 700 kW m^{-2}. These fluxes are well above those for which earlier instruments [1–3] were designed and so alternative methods are required. Several flux measuring concepts have been under development more recently, e.g. [4], but perhaps not enough allowance has been made for the effects of ash deposition. It has been shown in Part I of this paper that this can lead to substantial error.

The Central Electricity Research Laboratories have developed three instruments for measuring heat flux in boiler furnaces, each to fulfil different roles. During their development, careful account has been taken of the effects of ash. The first two instruments are designed for use as permanently installed devices to determine values of the heat flux absorbed locally by the boiler tube under the prevailing ash conditions. However, there is also a need to measure local values of incident radiation to determine flame radiation patterns. The third instrument has been developed for this purpose and is necessarily portable to allow the sensor surface to be kept free of ash. The three instruments are specifically:

1.1. *The Fluxtube*

This provides the most accurate and comprehensive measuring system [5]. In addition to absorbed heat flux, it can also be used to measure tube metal temperature and water/steam temperature.

1.2. *The Dometer*

This is a boiler tube surface-mounted device [6], suitable for installation in large numbers. It gives a measurement of tube metal temperature in addition to absorbed heat flux.

1.3. *The Fluxprobe*

This is a portable, entirely self-contained, direct-reading instrument [7] for measuring incident radiation from furnace flames. It is particularly suited to membrane construction boilers where it is small enough to pass through holes provided in the membrane or, of course, through any available boiler port.

2. DEVELOPMENT OF THE FLUX MEASURING INSTRUMENTS

All three instruments utilise the thermally guarded cylinder technique described in Part I for measuring heat flux. An integral part of each development has been a comprehensive analytical evaluation of its performance using the heat conduction computer program FLHE [8] applied to finite element models of the instruments. The necessity for this can be illustrated by consideration of the various heat-transfer processes involved.

The heat-transfer processes in a conventional boiler with clean boiler tubes can be represented by the following basic equations:

(a) Radiation heat transfer from the flame to boiler tube surfaces:

$$q = \sigma e(T_f^4 - T_{bo}^4).$$

(b) Conduction through the boiler tube wall:

$$Q = \frac{2\pi k_t(T_{bo} - T_{bi})}{\ln(r_o/r_i)}.$$

(c) Heat transfer to the water:

(i) Non-boiling.

Described by $Nu = 0.134Re^{0.65}Pr^{0.4}$[9].

(ii) Sub-cooled boiling.

Given by $T_{bi} - T_s = 0.7115\sqrt{q}/e^{P/86.874}$ [9]

where $q = h_s(T_{bi} - T_s)$.

However, in a real boiler the magnitude of the flux is inevitably modified by various factors, the principal one of course being the presence of ash.

For a guarded cylinder type of flux measuring instrument, when attached to the boiler tube, there are further conditions to be evaluated. The basic condition of the heat flow along a thermally guarded cylinder obeys the simple conduction equation:

$$q = k_m \frac{T_{mo} - T_{mi}}{a}.$$

In a practical device, perfect temperature matching between cylinder and guard will be impossible to achieve. Additionally, material thermal conductivities will vary with temperature. These complicating factors will also influence the basic calibration of the device and the relationship for determining tube surface temperature, which is frequently required in addition to heat flux. The basic equation for tube surface temperature, assuming perfect guarding of the measuring cylinder, is:

$$\frac{T_o - T_i}{x} = \frac{T_i - T_{bo}}{y}.$$

Thus the task of evaluating the thermal performance of these instruments is made complex by a number of factors and their interactions, and the only satisfactory method to investigate all these effects is to use heat conduction computer models.

The heat-transfer processes involved in the measurement of incident radiation heat flux are considerably simpler since ash is deliberately excluded. Nevertheless, computer models are essential to confirm the thermal performance of the instrument itself.

The three flux measuring instruments are described in turn.

2.1. *The Fluxtube*

The Fluxtube has been designed to provide a very accurate measurement of absorbed heat flux and additionally to provide measurements of boiler tube crown temperature and of water/steam temperature. The flux metering portion of the instrument is basically identical to the thickened tube concept discussed in Part I. The Fluxtube serves the role of a "standard" instrument against which other heat flux measuring devices may be compared.

The Fluxtube is illustrated in Fig. 1. It is constructed from a short length of boiler tube containing a locally thickened wall section incorporating a measuring cylinder and created by cranking or dimpling and weld deposition machined smooth, as described in Part I. Both the measuring cylinder and weld deposit are of 1% chrome and 0.5% molybdenum steel. The measuring cylinder is secured in a machined recess by vacuum brazing which also ensures intimate thermal contact between the inner end of the measuring cylinder and the bottom of the recess. This is essential to avoid distortion of the heat flow path in the cylinder which would affect its calibration, and to provide minimum surface temperature elevation of the cylinder above the boiler tube surfaces. For this latter reason also, the depth of cranking or dimpling, and hence the length of the measuring cylinder, is kept to a minimum consistent with obtaining an adequate temperature difference (and thus output signal) to suit the resolution of the normal power station data retrieval system.

Calculations showed the net tube internal flow

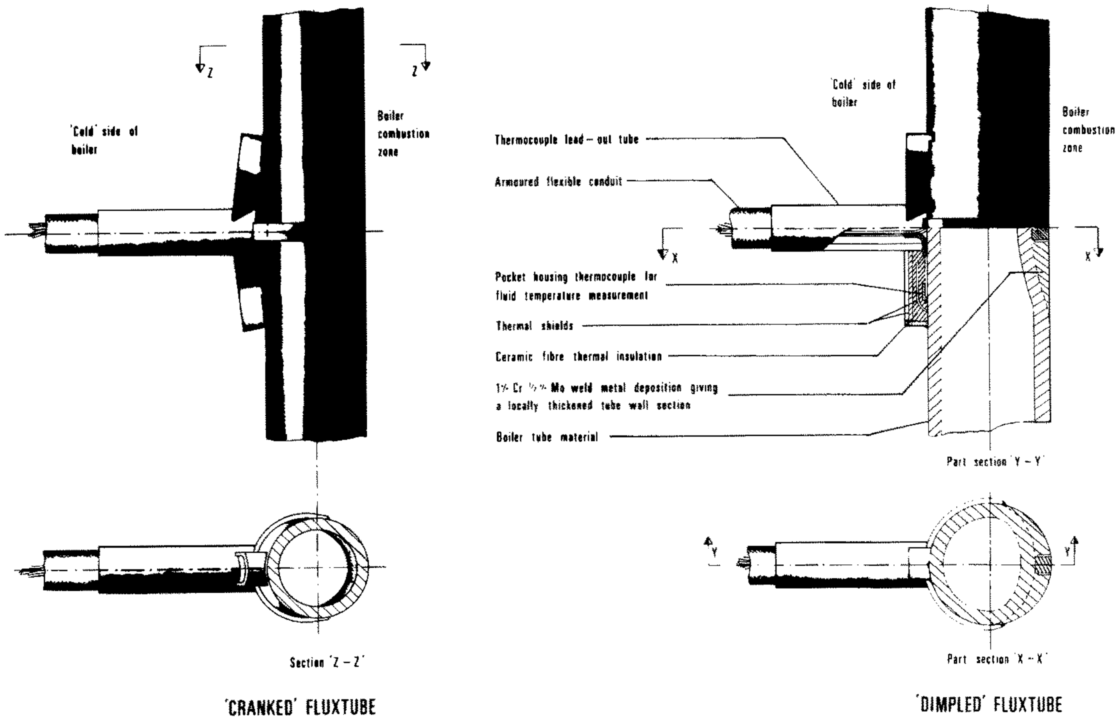

FIG. 1. 'Cranked' and 'dimpled' versions of the Fluxtube.

pressure loss to be negligible as a result of dimpling. This was confirmed by simple experiments, where eight dimples were formed in lengths of boiler tube and the overall pressure losses compared with unmodified tubes. The pressure loss of a single dimple was found to be equivalent to that of 0.05 m of plain tubing.

The measuring cylinder is fitted with two pairs of thermocouples in holes of known axial spacing to allow a cross check to be made of the heat flux. The thermocouples are 0.5 mm dia., Inconel sheathed, mineral-insulated nickel–chromium/copper–nickel and the hot junction ends are secured in the holes with a copper-based cement. The thermocouples are brought to the rear of the tube in slots machined in the weld-deposited material which are subsequently closed with shaped filler strips secured by surface welding. In this manner the pressure strength of the tube is unaffected.

Two further thermocouples are located in pockets at the rear of the Fluxtube to indicate water/steam temperature. These pockets are welded to the tube to provide good thermal contact and are insulated externally beneath an overall protective cover tack-welded to the tube. All six thermocouples are led away through flexible armoured stainless steel conduit to a junction box where the paired thermocouples are connected differentially to give two-flux-related EMFs, and the individually required thermocouple outputs measured after cold junction compensation through a reference unit incorporated in the junction box.

The performance of the Fluxtube has been confirmed theoretically using finite element heat conduction computer models. These have indicated that at a flux of 600 kW m^{-2}, it would operate with a surface temperature elevation of 75 K, producing a reduction in absorbed heat flux of 5 %, when coated with 1 mm of ash. This effect can be largely eliminated through calibration in oil-fired boiler applications, where ash deposit thicknesses are reasonably predictable, although changes in ash effective thermal conductance resulting from the temperature elevation make it impossible to eliminate it entirely. With this modest temperature elevation, it is anticipated that surface corrosion will not be a problem.

The computer model studies have also confirmed good thermal matching between the measuring cylinder and its surroundings, to the extent that the annular gap can be filled with a high temperature ceramic cement without affecting the calibration of the instrument. This gives increased protection to the delicate thermocouple cables which would otherwise be exposed to corrosive combustion products at this point. The computer models were also used to derive theoretical calibrations for the instrument relating to both heat flux (nominally 6.1 μV kW^{-1} m^{2}) and tube crown temperature, and furthermore, to confirm that the rear thermocouples give an accurate indication of water/steam temperature. A special furnace has been designed at CERL for individual calibration of boiler tube-mounted instruments at fluxes up to 600 kW m^{-2}.

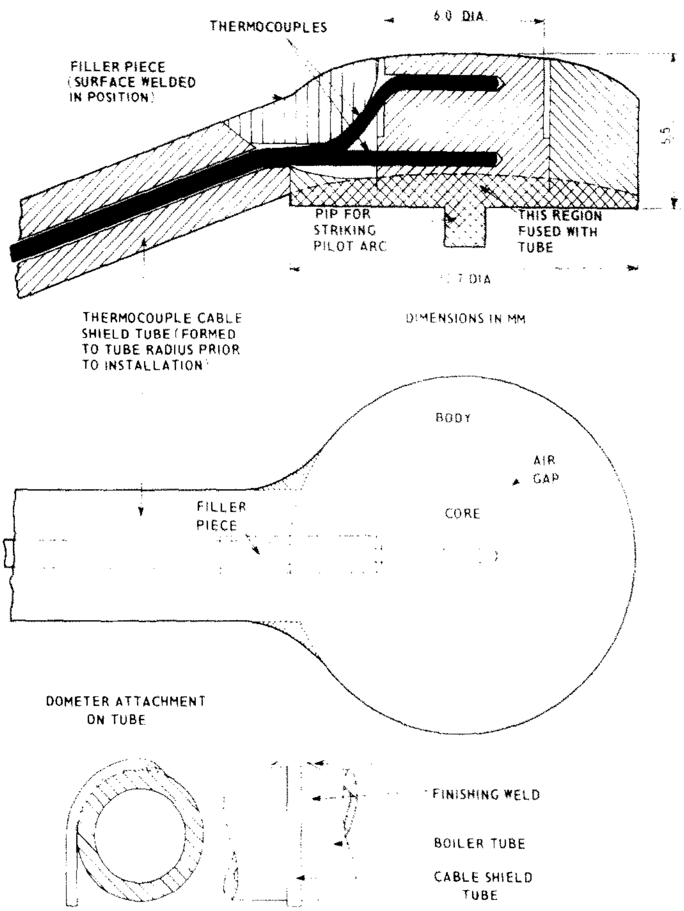

FIG. 2. Detail design of the Dometer.

Summarising, the Fluxtube installed in a boiler will provide continuous indications of local heat flux, boiler tube metal temperature and water/steam temperature under the correct ash emissivity and deposition conditions. The heat flux indications will probably be accurate to $\pm 5\%$.

2.2. *The Dometer*

The Dometer is a boiler tube surface-mounted instrument, so called because of its installed dome-shaped profile. It too can be used to indicate tube crown surface temperature in addition to absorbed heat flux. It is suitable for installation in large numbers for flux-mapping purposes, for basic design purposes, or for investigating flux-related problems in boilers.

A major problem associated with any tube surface-mounted flux measuring device is that of ensuring a good and uniform thermal contact between the device and the boiler tube which provides its heat sink. An attractive method would be to fuse the entire base of the meter into the tube surface. Such techniques are already well established in boilers for attaching studs to key refractory linings to tubes. The device would have to be designed to accept this method of attachment without risk of damage and at the same time to present an overall surface profile that would attract representative ash coatings. Preliminary stud-welding trials with special test pieces were very encouraging and development of the Dometer proceeded using this method of attachment. Once again, extensive use has been made of heat conduction computer models to assist in the development of the Dometer.

As with the Fluxtube, the Dometer utilises the guarded cylinder method of flux measurement. The guard consists of a concentric cylinder (body) separated from the measuring cylinder (core) by an annular gap over the majority of its length. The instrument is fabricated from stainless steel and the basic design is shown in Fig. 2. The two thermocouples are again of 0.5 mm dia. sheathed construction and are secured in the core by applying a controlled pressure to each end of the core. The thermocouple cables are contained within a protective tube which brings them from the Dometer core on the crown of the boiler tube to the outside of the furnace between adjacent tubes. The leads are connected in a termination box to give a differential flux-related EMF and an individual thermocouple EMF for tube surface temperature measurement.

The commercial stud welding technique has been modified for the purpose of attaching Dometers to boiler tube surfaces. The standard equipment has a predetermined sequence of operations whereby the stud to be attached is momentarily drawn away from the workpiece to form a pilot arc. The current is then immediately reinforced to the full value causing both the end of the stud and the related region of the workpiece to fuse. The stud is rapidly propelled into the molten pool to provide a void-free weld, and the welding current interrupted to complete the weld.

For Dometer attachment the welder hand tool has been extensively modified and the control system considerably augmented to include an automated welding procedure which both simplifies the welding operation and reduces as far as is practicable the risk of an unsatisfactory weld. A large number of weld specimens have been examined metallurgically and found to be satisfactory.

Having welded a Dometer in position, a finishing fillet weld is run around the body and along each side of the exposed cable shield tube as shown in Fig. 2. This fillet weld gives the Dometer its overall dome shape, which is considered to be the profile for a surface mounted device most likely to collect a representative thickness of ash.

With a device of this design, it is evident that perfect temperature matching between core and guard is not possible. The effect of this on calibration was just one aspect studied on the three-dimensional heat conduction computer model of a half-section Dometer on a quadrant of boiler tubing, reproduced in Fig. 3. The model includes a 1 mm thick layer of ash and other features as shown. The performance evaluation of the Dometer was a much more complex problem than was the case for the Fluxtube, primarily because the guard effectiveness was less predictable and possibly influenced by factors such as fillet weld profile.

The theoretical studies had the following main objectives:

1. to determine a suitable core diameter such that the 0.5 mm dia. thermocouples would not distort the core temperature distribution,
2. to determine the core, air gap and guard configurations to reduce to a minimum any interchange of heat between core and guard,
3. to determine the theoretical calibration for the device when coated with ash,
4. to examine the effect on calibration of filling the air gap with a high temperature ceramic cement to give increased protection to the thermocouple cables,
5. to examine the sensitivity of the calibration to the fillet weld profile, and
6. to examine the sensitivity of the calibration to any voids within the weld zone beneath the meter.

Briefly, the studies showed the calibration to be affected by less than 2% by any likely variations in fillet weld angle and by voids in the weld zone, unless one occurred immediately in line with the thermocouple hot junctions — a most unlikely event. Filling the annulus with cement produced an 11% change in calibration, but as this change could be entirely predictable and permanent it is of no consequence. The theoretical calibration in simplest terms, taking into account the manufacturing and installation tolerances, approximates to $6\,\mu V\,kW^{-1}\,m^2 \pm 10\%$. This takes no account of any changes in ash effective thermal conductance due to meter surface temperature elevation, which is of order 150 K at a flux of $600\,kW\,m^{-2}$. Obviously this could be significant and is best evaluated in practical boiler trials. This temperature elevation might also lead to corrosion problems which again can only be evaluated in boiler trials. These formed the final stage of this entire investigation.

2.3. *The Fluxprobe*

The Fluxprobe is a portable, entirely self-contained, direct-indicating instrument providing a quick and convenient means of measuring local values of the

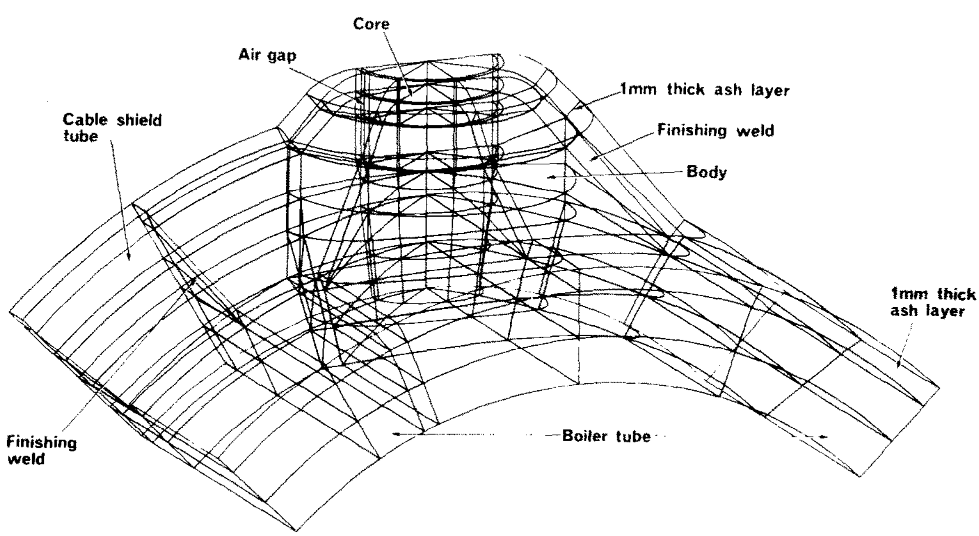

FIG. 3. Finite element representation of a Dometer half-section mounted on a boiler tube.

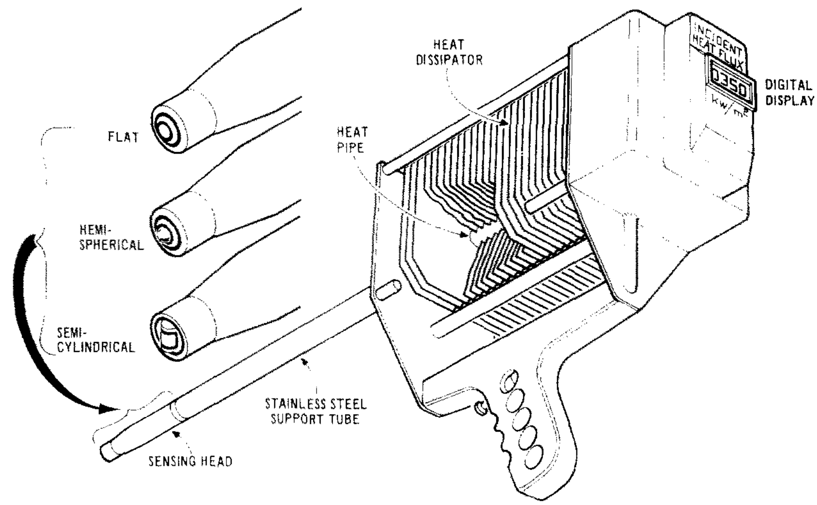

FIG. 4. The Fluxprobe, including alternative sensor surface profiles.

incident radiation heat flux from boiler furnace flames. It has been designed primarily for use in membrane construction boilers (the current design) wherein adjacent boiler tubes are joined along their length by a continuous membrane some 13 mm wide and 6 mm thick. The sensing head of the Fluxprobe is small enough to insert through 0.25 in. BSP tapped holes in the membrane. Alternatively, the Fluxprobe may be used through any available boiler port.

A drawing of the Fluxprobe is shown in Fig. 4. The sensor head is again of guarded cylinder construction, but with the difference that a double guarding arrangement is used. The computer model studies of the sensor head indicated that with both the tip and sides of the head exposed to radiation, a single annular gap resulted in a very considerable temperature mismatch between core and guard, such that the calibration was sensitive to the penetration of the head into the furnace. The provision of a second annular gap reduced this effect to a maximum change in calibration with penetration of 4%. The material chosen for the prototype head was steel type EN 56A, which has a virtually constant thermal conductivity over the anticipated operating temperature range; this, together with the use of nickel–chromium/nickel–aluminium thermocouples having a near-linear temperature/EMF characteristic, ensured a virtually constant calibration over a wide range of flux.

In order to obtain an accurate measurement of incident radiation heat flux, it is essential that the sensor surface temperature is low so that reradiation is negligible. For example, at an incident heat flux of 500 kW m^{-2}, a sensor surface temperature of 600°C produces a reradiation component of 6.6% and this rises to 15% at 800°C. In the Fluxprobe, a low surface temperature is achieved by using a heat pipe to provide a very low resistance heat path between the sensing head and a finned natural convection heat dissipator. The spaced thermocouples are connected via electrical circuitry to a digital display calibrated in kW m^{-2}. In the prototypes a digital thermometer has been modified for this purpose. A simple error analysis on the Fluxprobe indicated that it should be capable of measuring incident radiation heat flux to within ±5%.

The sensor receiving surface has been coated with a layer of nickel oxide, using a hot metal spraying technique, in order to give it a stable, high emissivity (0.95). The prototype Fluxprobe has a flat receiving surface and has a 'cosine law' shape of absorption pattern. Two further prototypes were made having semi-cylindrical and hemispherical receiving surfaces (see Fig. 4), but no significant differences in measured heat flux between the three prototypes were observed during subsequent boiler trials. Thus the flat receiving surface is considered entirely suitable for boiler furnace applications and has been adopted for the final version of the Fluxprobe. Calibration of the Fluxprobe is performed using a high temperature (1550°C) black body furnace. The small reradiation component can be effectively eliminated by adjusting the calibration to suit a sensor surface temperature of 0 K.

Figure 5 shows photographs of the three flux measuring instruments. The top photograph depicts the Fluxtube with its termination box, the middle photographs show a Dometer mounted on a section of membrane wall boiler tubing with the rear view showing the termination box arrangements, and the bottom photograph shows the prototype Fluxprobe in use at an oil-fired power station.

3. BOILER TRIALS

A total of five Fluxtubes and 21 Dometers were installed in a localised high flux region in an oil-fired power station boiler, and a further nine Dometers were installed in a coal-fired boiler in a region of appreciable slagging. The special calibration furnace was not available for the instruments used in these boiler trials, and so the theoretical calibrations had to be employed. However, a quartz–halogen lamp was used to provide a simple reference radiation source enabling the out-

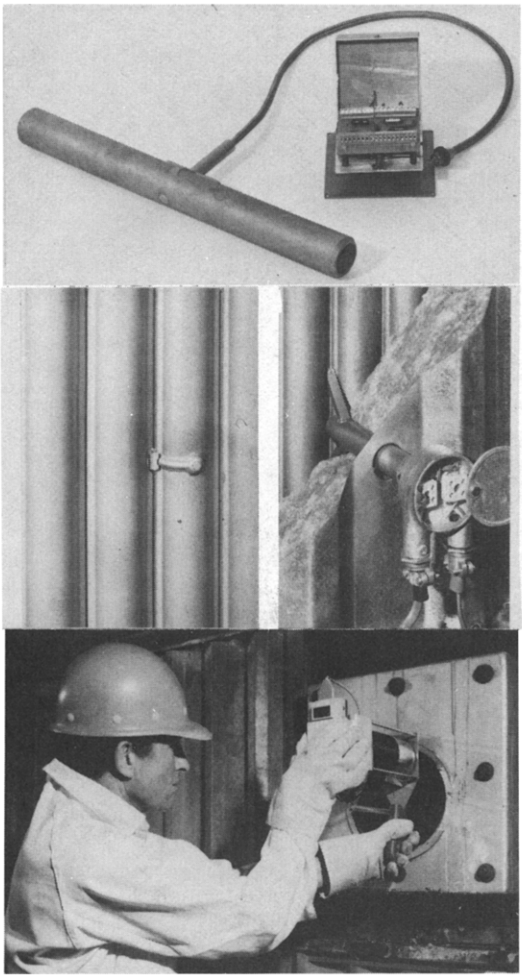

FIG. 5. Photographs of the Fluxtube, Dometer and Fluxprobe.

puts of individual meters to be compared prior to installation in the boiler. This check showed that individual calibrations were within $\pm 10\%$ of the mean for both Fluxtubes and Dometers. Individual outputs during the boiler trials were subsequently corrected to take account of their comparative calibration. Approximately 80 access points for Fluxprobe trial measurements were provided, spread over boilers at three coal-fired power stations. The oil fired boiler trial was terminated after 10 000 h of firing. Over this period one Fluxtube and one Dometer became inoperative through thermocouple failure. In both cases the reasons for failure were established and steps taken to ensure that no further failures would occur from these causes.

A single set of data from the oil-fired trial was collected daily by data logger on site and then analysed subsequently by computer. The trial showed that Fluxtubes and Dometers were in good agreement over the entire period of the trial, indicating that Dometers collected a representative thickness of ash and that surface temperature elevation effects were small. Throughout the trial there were random fluctuations in individual measured heat fluxes of order $\pm 10\%$ when normalized with respect to the average of the five Fluxtubes. These variations, which were both temporal and spatial, would be caused by flame fluctuations, short and long term ash changes, burner configuration changes, load changes, etc. Inevitably, these fluctuations appear in any comparative analysis that might be made as the devices, whether they be Fluxtubes or Dometers, are measuring the instantaneous values of heat flux into that small region of the tube. During periods of frequent stoppage, these variations were more significant and it appeared that differential thermal expansion between ash deposits and boiler tubes caused the former progressively to spall over a two or three day period.

During periods of continuous operation, the ash deposits appeared to reach a quasi-equilibrium condition, which manifested itself through much smaller flux fluctuations. The mechanism of this equilibrium condition must be to some extent conjectural, but it seems probable that as the ash layer thickens, its surface temperature increases rapidly until the outer surface becomes molten and runs down the tube surfaces, to be continuously replenished by fresh deposits.

Under normal boiler operation, the range of fluxes to which boiler surfaces are subjected is somewhat limited, being mostly in the range 400–600 kW m^{-2}. In order to obtain performance data for the flux meters over a wider range of fluxes, their outputs were also monitored during several boiler starts during the initial part of the trial, enabling fluxes as low as 40 kW m^{-2} to be measured. Data for a typical Dometer are summarised in Fig. 6, which shows the indicated flux compared with that from the five Fluxtubes. The individual test points cover the initial 2000 firing hours whilst the mean and 95% confidence lines are derived from the trial as a whole apart from the start-up measurements.

The Dometers installed in a coal-fired boiler have performed equally satisfactorily over a period approaching 8000 h at the time of writing. Indicated fluxes were generally lower, and much more variable, than in an oil-fired boiler. Maximum fluxes approach 400 kW m^{-2} but were often as low as 50 kW m^{-2} with the boiler operating at full load, probably due to heavy ash deposits. Short term fluctuations were typically of the order of $\pm 25\%$ but with occasional much larger variations. During one period of continuous monitoring there was a step increase in flux of 800% indicated by several Dometers, resulting no doubt from the departure of an area of slag from the furnace wall. In neither trial to date has an opportunity arisen to inspect or remove any Dometers or Fluxtubes in order to assess the extent of any corrosion. The evidence from the trials however is that no serious corrosion has occurred.

The Fluxprobe has been tested in several power station boilers including the coal-fired boiler fitted with Dometers. Several access points were drilled through the membrane wall adjacent to Dometers. It was necessary to dislodge ash and slag from the

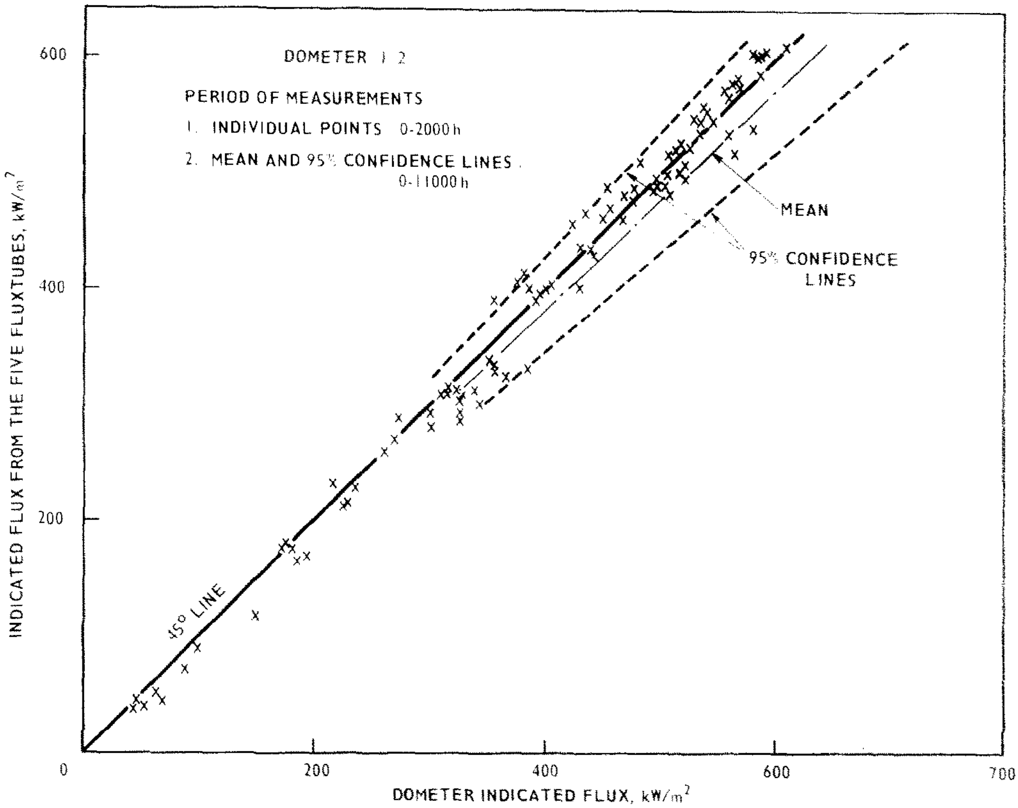

FIG. 6. Comparison between the indicated flux from the five Fluxtubes and that indicated by an individual Dometer.

vicinity of each location with a simple tool prior to each Fluxprobe measurement. As would be expected, incident fluxes were always higher, and more stable, than the adjacent Dometer absorbed heat flux measurements.

More comprehensive trials of the Fluxprobe on another coal-fired boiler confirmed its satisfactory performance. The Fluxprobe took approximately 20 s to stabilise for each flux measurement, and a boiler survey of 25 individual measurements could be completed in half an hour. Incident fluxes were in excess of $500\,kW\,m^{-2}$ opposite the burner region, falling to below $200\,kW\,m^{-2}$ in the corners of the boiler at the same level. The surface temperature of the Fluxprobe approached 500°C at the highest fluxes measured, which would result in a reradiation of incident flux of 3–4%. This amount can safely be corrected for in the initial calibration of the instrument. More recently the Fluxprobe has been used extensively and very successfully in investigations relating to problems of slagging and of fire-side corrosion in coal-fired boilers.

4. CONCLUSIONS

The development of instrumentation for the accurate and reliable measurement of heat flux in boiler furnaces necessitates a thorough knowledge of the factors affecting the measurement, particularly the effects of ash deposition.

An integral part in the development of a successful flux measuring device is a detailed computer model evaluation to include an investigation of the sensitivity of its calibration to all the likely variables.

Three heat flux measuring instruments have been developed for use in boiler furnaces, each fulfilling separate roles: the Fluxtube gives very accurate (within $\pm 5\%$) measurements of absorbed heat flux as well as measuring tube and water/steam temperatures; the Dometer is suitable for installation in large numbers and measures absorbed heat flux (to within $\pm 10\%$) and tube temperature; the Fluxprobe is a portable self-contained instrument for measuring total incident radiation from furnace flames to within $\pm 5\%$.

These instruments have undergone extensive boiler trials which have demonstrated their accuracy and ability to withstand the hostile environment over an extended period.

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LA MESURE DU FLUX THERMIQUE RAYONNE DANS LES GRANDS FOYERS DE CHAUDIERES—II. DEVELOPPEMENT DES INSTRUMENTS DE MESURE DE FLUX

Résumé—Pour répondre aux besoins, deux instruments installés de façon permanente ont été conçus pour mesurer le flux thermique absorbé par les tubes de chaudière ainsi qu'un instrument portatif pour mesurer le rayonnement incident des flammes. La performance thermique de chaque instrument a été étudié avec soin à l'aide de modèles de calcul. Des essais très étendus de ces trois instruments indiquent qu'ils sont précis et donnent des méthodes de mesure des flux thermiques dans des foyers de chaudière.

DIE MESSUNG DES STRAHLUNGSWÄRMESTROMS IN GROSSEN VERDAMPFER-HEIZFLÄCHEN—II. ENTWICKLUNG VON WÄRMESTROM-MESS-INSTRUMENTEN

Zusammenfassung—Um den Anforderungen eines Kraftwerks zu entsprechen, wurden zwei fest installierte Instrumente zur Messung des von den Verdampfer-Rohren absorbierten Wärmestroms und ein transportables Gerät zur Messung der einfallenden Flammenstrahlung entwickelt. Das thermische Verhalten eines jeden Instruments wurde gründlich mit Hilfe von Computer-Modellen untersucht. Mit den drei Meßgeräten wurden ausführliche Versuche durchgeführt; dabei zeigte sich, daß sie genaue und zuverlässige Meßverfahren für den Wärmestrom in Verdampferheizflächen ermöglichen.

ИЗМЕРЕНИЕ ЛУЧИСТОГО ТЕПЛОВОГО ПОТОКА В ТОПКАХ БОЛЬШИХ ПАРОВЫХ КОТЛОВ —II. РАЗРАБОТКА ПРИБОРОВ ДЛЯ ИЗМЕРЕНИЯ ВЕЛИЧИНЫ ТЕПЛОВОГО ПОТОКА

Аннотация — Дано описание двух стационарных приборов, разработанных для измерения теплового потока, поглощаемого трубами котлов электростанций, и портативного прибора для измерения величины лучистого потока в топках. Путем моделирования на электронно-счетной машине детально исследованы тепловые характеристики каждого прибора. Все три прибора прошли тщательные испытания, которые показали точность и надежность полученных результатов измерений.