Ulf Wickström

A PROPOSAL REGARDING TEMPERATURE MEASUREMENTS IN FIRE TEST FURNACES

Nordtest Project 355-82

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ABSTRACT

A PROPOSAL REGARDING TEMPERATURE MEASUREMENTS IN FIRE TEST FURNACES

Two devices are introduced for measuring temperature in fire test furnaces, the plate thermometer and the globe thermometer. They are both sensitive to levels of irradiance like test specimens while ordinary thermocouple beeds are more sensitive convective heat transfer. It is suggested that these devices are specified in new furnace standards like ISO 834.

Key words: thermometer, furnace test.

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SUMMARY

Two simple probes are developed to characterize the thermal conditions in fire test furnaces. One probe, the globe thermometer, consists of steel globe with a thermocouple in the centre and gives general information on the thermal conditions in a furnace. The other, the plate thermometer, consists of a thermocouple welded to a steel plate which is insulated on one side. The plate is intended to be placed near the specimen facing the furnace. It will thereby receive the same thermal irradiance on one side as the specimen; the other side is insulated and will protect it from irrelevant radiant heat transfer from the specimen. Both probes are made rather big, in the order of 100 mm, and will therefore be sensitive to convective heating in a similar way as a specimen of normal size. The exposed plate is only 0.7 mm thick and will therefore respond quickly to thermal changes. Theoretical calculations show that it will in an ideal furnace with an emissivity near unity follow the ISO 834 standard curve within a few degrees except for the first few minutes. It can therefore be used to monitor and control the heating conditions in a furnace. With thinner steel globe and thermocouple than used here the globe thermometer will be faster and can as well be used for controlling fire test furnaces instead of bear thermocouple as specified by ISO 834.

The main object of the two probes are to make it possible to compare the heating impact to the specimen in various fire test furnaces when operated according to standard specifications. Gas temperature measurements as specified in ISO 834 and similar standards

give by no means a adequat information of the thermal exposure imposed to a specimen. The high temperature levels imply that the thermal irradiance controlls the heating of the specimen. The thermal properties of the furnace walls, the furnace geometry as well as the burner properties will therefore have significant influence. Particularly in the beginning of a test the specimen will "see" a cool rear wall while the thermo-couples for controlling the heating conditions are surrounded by hot gases. If these then are sensitive to convective heating , as small bodies in general are, they will adjust to the gas temperature and not to the irradiance level. This phenomenon is particularly important in narrow gasheated furnaces. The globe- and plate thermometers are, however, not so sensitive to convective heating but more to radiative heating, and will therefore show much more representative temperature values.

The probes are cheap to manufacture, robust and easy to use.

HEATING CONDITIONS VARY BETWEEN FURNACES

It is well known that various fire test furnaces may expose the specimen to heating conditions that differs although the same standard, ISO 834, is employed. The standard prescribes a time temperature relation that shall be followed during a test. The temperature is recorded by bare thermocouples that are placed in the furnace near the specimen. These thermocouples are in a dynamic thermal equilibrium with its environment.

Heat is transferred by both radiation and convection from the furnace atmosphere. Also the surrounding walls influcence the thermocouple temperature and in general there is a difference between the wall and gas temperatures. Particularly if burner flames are presented the gas temperature may differ much from the corresponding radiation level.

Several furnace parameters will influence the temperature reading. The convective heat transfer rate for instance depends on the local gas velocity and the geometric size and form of the thermocouple beed. The radiation heat transfer, on the other hand, varies with the radiation intensity of the furnace gases, the size of the furnace, the presence of luminouse flames in the furnace and the wall temperature; the latter depends on the thermal inertia of the furnace wall lining material.

The specimen is much larger than the thermocouple beed and is therefore relatively more sensitive to radiation exposure than a thermocouple of the kind prescribed in ISO 834. Therefore as the characteristics of existing fire test furnaces vary considerably the thermal exposure of a specimen during a test may vary although the same specified time temperature relation is followed. The problem has been discussed extensively for many years. Suggested recommendation to avoid the problems are among others:

1) Line the furnaces with materials of low thermal inertia.

2) Measure the temperature with suction pyrometers to get the true gas temperature.

3) Measure the incident radiation to the specimen.

The first recommendation has several advantages. It reduces the temperature differences inside the furnace as well as the energy input needed to follow the prescribed temperature.

The second recommendation is, however, more doubtful. At the high temperature levels the heat transfer to the specimen is first of all dependant on the radiation level and therefore it is not of major interest to control the true gas temperature precisely.

The third recommendation is of greater interest, but suffers from the fact that it is difficult to measure irradiation. Available instruments are not practical in the daily test work as they are not very robust and are rather laborious to use and calibrate.

An alternative way of measuring irradiation was suggested for the first time at the CIB W14 meeting in 1978 by the author. Instead of a small thermocouple beed a larger body relatively more sensitive to radiation heat transfer was proposed as a temperature sensor. Hadvig /1/ introduced the globe thermometer in 1981 and also at the CIB W14 meetings in 1982 /2/ and together with Hansen in 1984 (CIB/W14/84/10(DK)); the latter is appended to this report. Briefly the proposed globe is made of a stainless steel ball with a diameter of 115 mm with a bare thermocouple inside.

The two papers present theoretical comparisons of temperatures reached by the globe thermometer and the standard thermocouple at various furnace conditions and radiation levels.

In this paper the emphasis will be focused on an alternative design of an enlarged temperature probe or simple radiometer, the "plate thermometer". A draft report on this concept was first presented at the CIB W14 meeting in 1984. Since then the design of the probe has been slightly changed.

THE PLATE THERMOMETER THERMALY SIMULATES THE SPECIMEN

A temperature probe for furnace tests shall have the following main properties.

a) Be sensitive to radiative heat transfer rather than convective heat transfer like a furnace test specimen.

b) Have a fast response.

c) Be easy to use and calibrate.

d) Be durable and resistant to the standard fire conditions.

All these requirements are more or less satisfied with a plate with the dimensions of 100 mm x 100 mm as shown in Fig. 1; an even larger plate would be impracticle and would interfere with the heat exposure of the specimen.

The influence of radiation heat exchange between the specimen itself and the plate is eliminated by insulating the surface facing the specimen. Thus the specimen and the sensor, when placed near the specimen, will approximately be exposed to the same incident irradiation.

The response characteristics, sometimes referred to as the time constant, depends on the thickness of the plate. For controlling purposes a relatively fast response instrument is desired. Thin plates are, however, inclined to warp and buckle and therefore the plate is supported along the edges by a box structure as shown in Fig. 1. A large hole is made in the rear plate so that the thermocouple can be welded on to the front plate. An insulating ceramic pad is then placed inside the box to protect the front plate from being exposed to heat transfer from more than one direction.

The front plate is made of a 0.7 mm thick Inconel 600 steel plate. The thermocouple is Inconel shielded with a outer diameter of 1.0 mm and spot welded at the end to the centre of the front plate.

After being used a couple of times in the furnace the steel surface turns black and achieves an emissivity in the range of 0.7 to 1.0, se next chapter.

It is experienced at the National Testing Institute (SP) that the plate here described is robust and can be used several times in standard furnace tests without being weared out.

THE TIME RESPONSE CHARACTERISTICS WAS EVALUATED

In addition to the relative sensitivity to radiative and convective heat transfer, the speed of the temperature response characterizes a probe; a probe with a large area to volume ratio times a high effective heat transfer coefficient will have a fast response and vice versa. A slow probe is not suitable for controlling the heating conditions.

To evaluate the time response characteristics a plate thermometer was heated to 800 °C in a small furnace, and then taken out and cooled in room temperature. The time temperature history was recorded. A theoretical analysis was then carried out using the computer program TASEF-2 /3/ and theoretical and experimental results were compared. The effective thickness was assumed 0.8 mm and the convective heat transfer q_c was calculated as

$$q_c = \beta \, (T_p - T_\infty)^\gamma$$

where T_p and T_∞ are the plate and ambient temperatures, respectively. The convection parameters β and γ were obtained from a textbook /4/ by assuming free convection from a vertical plane and then assuming that the thermal properties vary with temperature according to a simple polynomial expression /3, 5/. Values for β and γ obtained for a 10 mm vertical plate were 2.25 and 1.33, respectively.

Various values of the emissivity ε were then tried and it was found that the best fit between measured and calculated temperatures was obtained for ε = 0.8, see figure 2.

This value of the emissivity was then used to calculate the thermal response of the plate when exposed to the ideal ISO 834 standard furnace conditions. The heat transfer to the plate q was then calculated as

$$q = 0.8 \ \sigma \ (T_f^4 - T_p^4) + 25 \ (T_f - T_p)$$

where σ is the Stefan-Bolzmann constant, and T_f and T_p are the absolute furnace and plate temperatures, respectively. The convective part of the heat transfer is in this case small in comparison with the radiative part and need therefore not be modelled so carefully. A linear relation is therefore assumed with the convective heat transfer coefficient was assumed equal 25 W/m^2K.

The results of the calculation is plotted in figure 3. As can be seen the probe is reasonably fast and can therefore be used for controlling a furnace during a fire test.

THE PLATE THERMOMETER REVEALS LOWER HEATING CONDITIONS

Both the globe- and plate thermometers have been used several times in the vertical test furnace at SP. As can be been in figure 4, the thermometers show lower temperature then the ordinary furnace thermocouple.

For the plate thermometer this difference in temperatures is mainly due to the relatively low irradiance level in the beginning of the test as the rear walls are still much cooler then the gas. The greater difference recorded by the globe thermometer is due to its slower time-temperature response; the thickness of the globe was 1.0 mm and the thermocouple beed 1.0 mm. The globe is particurlarly slow at low temperature, as heat transfer to the beed is by radiation. At high temperature the response characteristics are dependent on the probe dimensions in a similar way as the plate thermometer. In addition the globe is influenced by he radiation level from the specimen side of it.

The furnace used at SP is oil fueled and rather deep. Similar test as here reported are currently also run at the other Nordic fire laboratories and it is believed that they will give some interesting information on the various furnace characteristics.

RECOMMENDATIONS

To evaluate the credits of the proposed way of measuring furnace temperature, tests in furnaces of various characteristics must be carried out and the ability of the proposed plate thermometer to improve reproducability must be investigated. Additional measurements could for instance be done with the thermometers in any standard test and the recorded temperatures compared and analyzed. It is therefore suggested that the plate and/or the globe thermometer is introduced in furnace test standards like ISO 834

(NT FIRE 005) to be used optionally to gain experience. A good basis for evaluating the reproducability of furnace test results could then be obtained and the experience could probably facilitate acceptance of test results between fire technical laboratories.

Plate thermometers could be obtained from SP for a price of USD 150.

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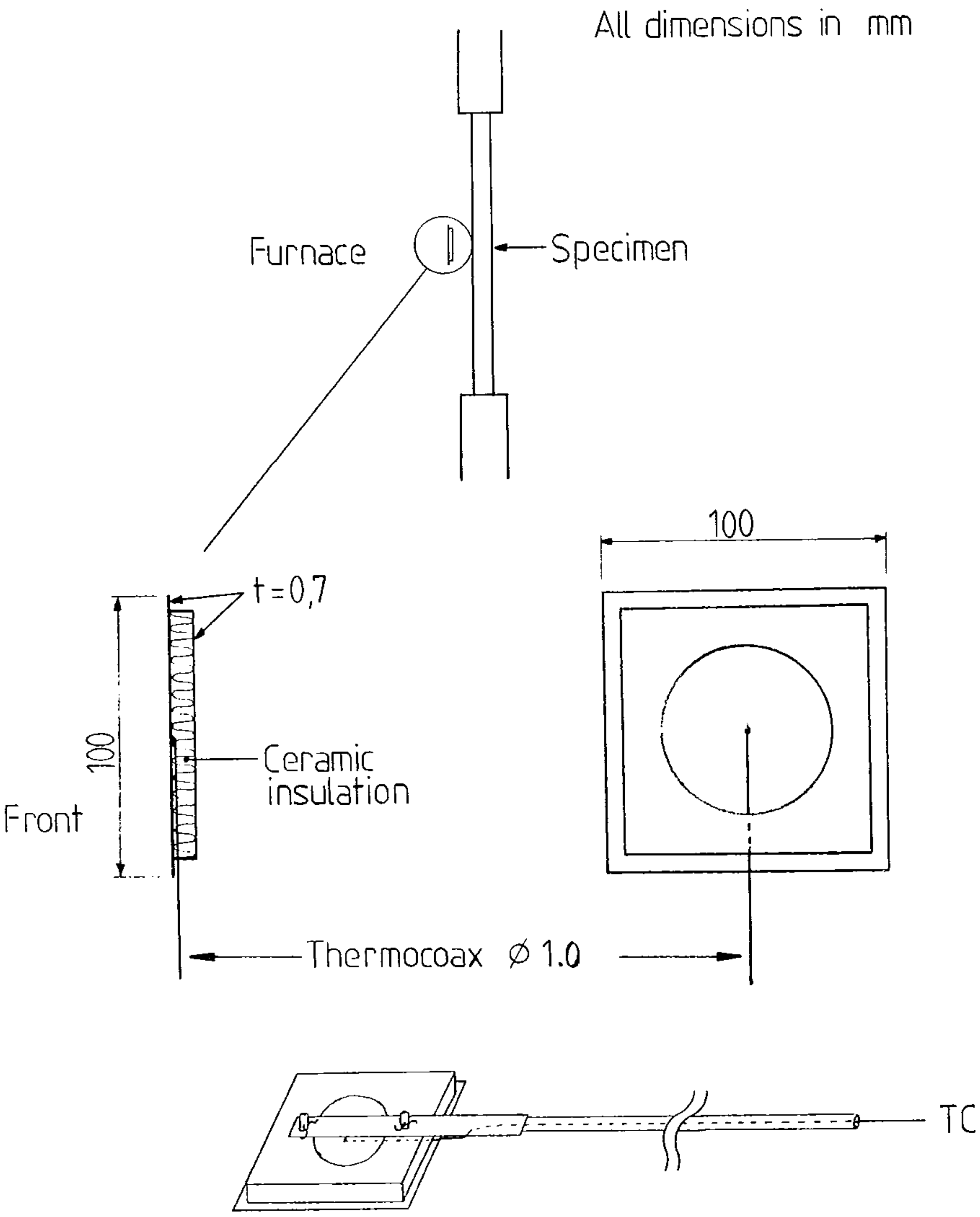

Figure 1. Plate thermometer. Location and orientation near specimen, section, rear view, and perspective with mounting tube.

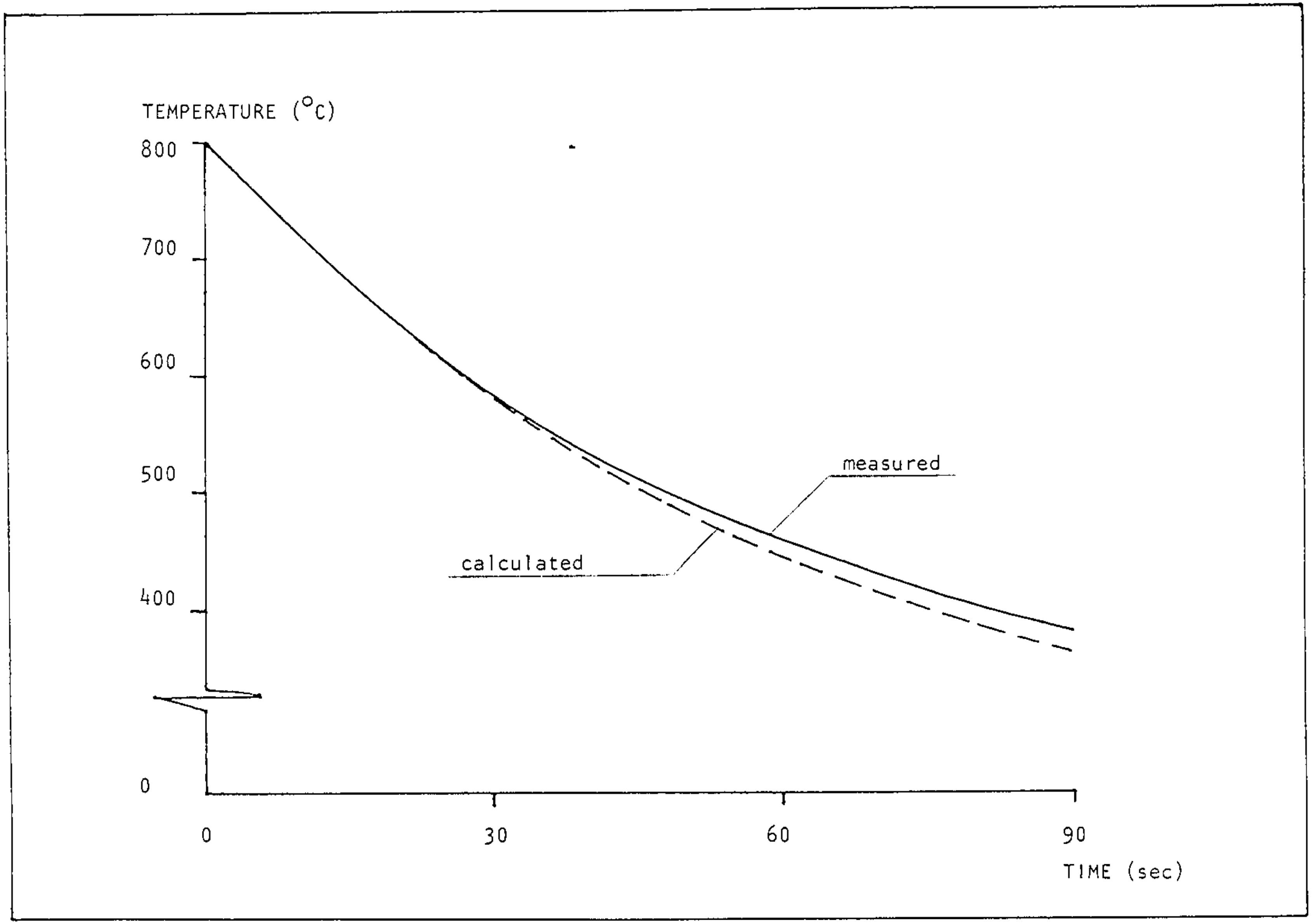

Figure 2. Calculated and measured temperature histories of plate thermometer cooled in ambient atmosphere. The emissivity and the effective plate thickness were chosen to be 0.8 and 0.8 mm, respectively, to obtain best agreement. The convective heat transfer properties were obtained from textbooks.

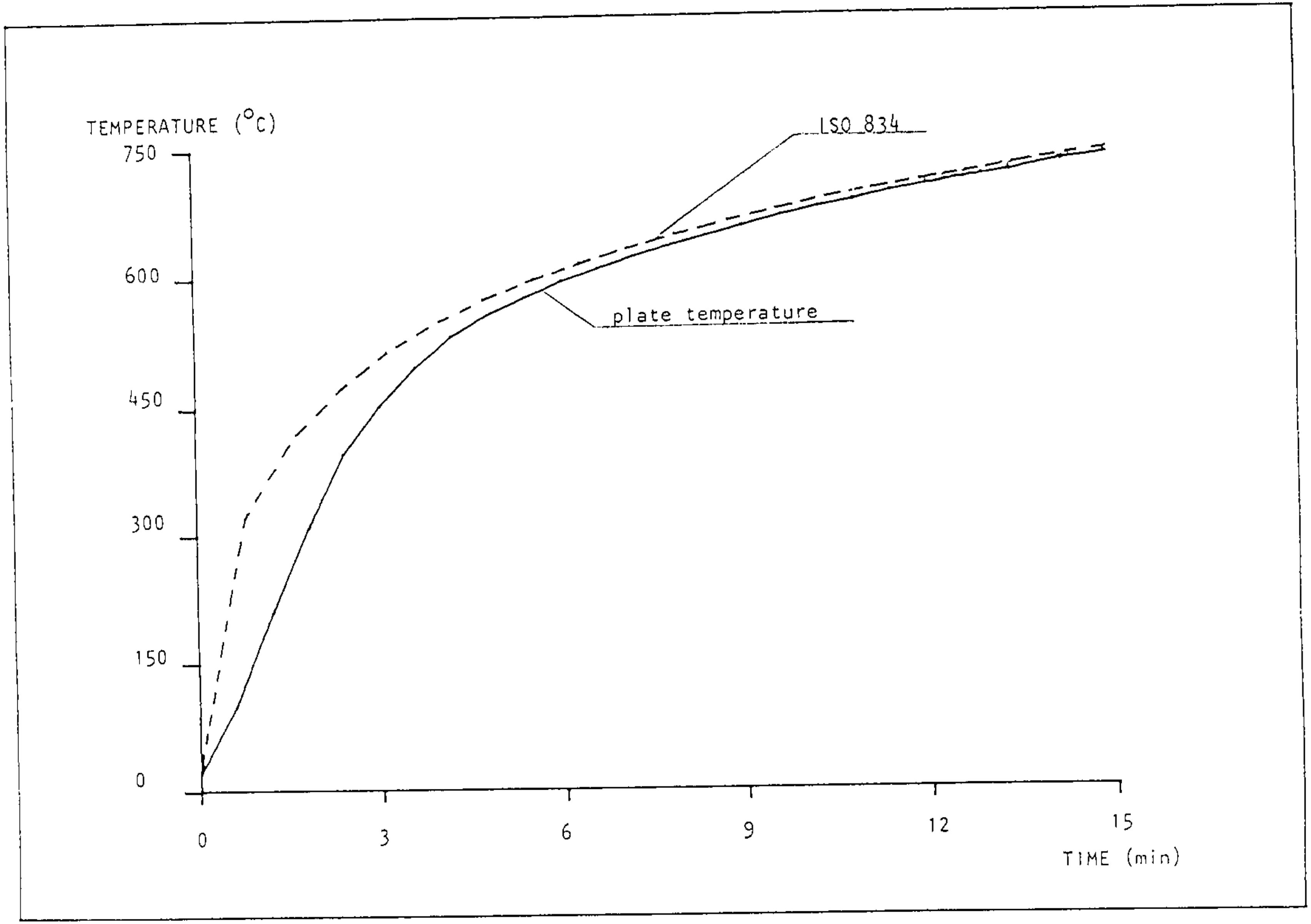

Figure 3. Calculated time temperature history of the plate thermometer exposed to the ISO 834 standard curve under ideal conditions. The resultant emissivity and the effective plate thickness are assumed equal 0.8 and 0.8 mm, respectively.

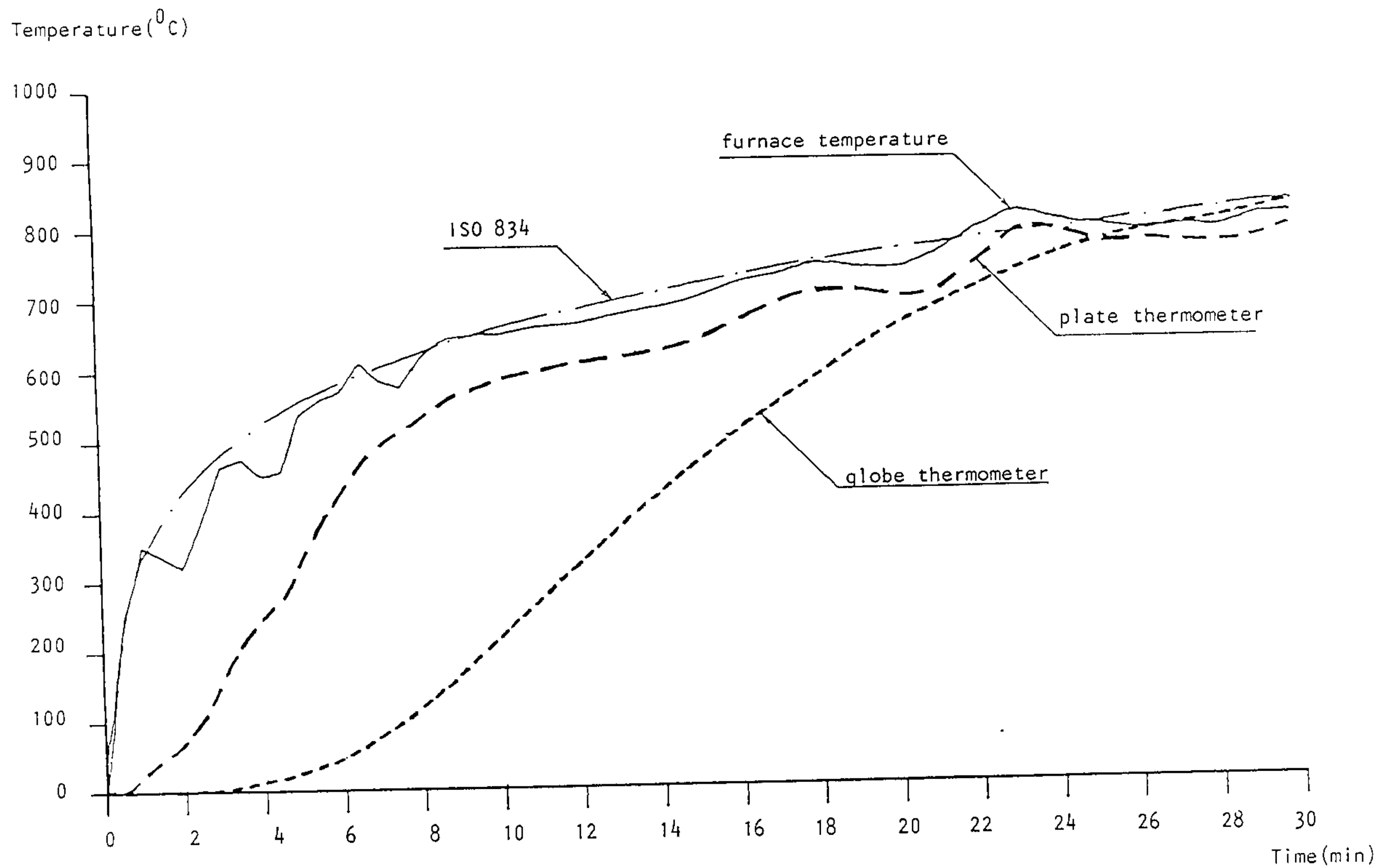

Figure 4. Time temperature histories measured in a furnace with a globe thermometer, a plate thermometer and a thermocouple complying with the ISO 834 standard, i.e quick tip Ø 0.8 mm.

CIB/W14/84/10(DK)

CIB-W14 MEETING IN BOREHAMWOOD, MAY 1984.

Measurement of Radiation in Fire-Test Furnaces: Proposals.

Sven Hadvig and Michael Hansen.

The main points of the proposals

The statement given in this paper concludes in four proposals for amendments of ISO 834 as listed below. More detailed arguments in favour of these proposals can be found in [1]. The proposed amendments may be introduced separately or collectively. A brief mention of the legal and commercial difficulties arising in connection with such amendments of ISO 834 will be given later in this paper.

(I) For the control of fire-test furnaces a globe thermometer placed in the geometrical centre of the furnace (though not right in the jet flow from the burners) should be substituted for the present thermocouples that follow the ISO temperature-time curve at a distance of 10 cm from the specimen.

(II) Brick-built fire-test furnaces should be lined with a lightweight lagging a few centimetres thick, e.g. Kaerwool.

(III) The application of simple flux meters (plate-shaped) for an approximate determination of incident radiation on, e.g. a wall element was tested and will be described below. An aged and calibrated thermocouple was used. It is crucial that the thermocouple be brought into contact with the front plate of the meter without welding, otherwise the thermocouple reading will not be reliable. Consequently, thermocouple and measuring device must be separated. The thermocouple should be calibrated by a qualified institute. If the thermocouple is welded in the meter both will have to be calibrated and this is an extremely difficult process that should be avoided.

(IV) A box-shaped flux meter to be used in the furnace for the testing of beams and/or columns was suggested by Harmathy. Ageing and calibration of four thermocouples as mentioned under (III). It is difficult, however, to mount thermocouples in the correct position in the measuring box.

Introduction

Fire-test furnaces are used for comparisons between the external (outside the fire-test furnace) surface temperature of building structures, their fire resistance, etc.

The development of new building constructions has given rise to a desire for a better possibility of calculating the behaviour of a structure when exposed to fire in a test, and thus of knowing whether it will be approved. Very often considerable amounts are invested in the development of prefabricated structures, so it is natural for the manufacturing industry to want to know how a structure will behave in a test. As designers, through training and experience, become better at calculating, and better EDP-programs are developed for this work a development will take place in this field.

As fire engineering design develops the manufacturing industry will know how to use the results from the fire-test furnaces also for a prediction of the behaviour of a structure when exposed to fire in circumstances different from those in the fire-test furnace.

It is a condition, however, that the designer knows the thermal exposure to which his construction was subjected during the fire test. Normally, this is not the case today, but it is necessary for fire engineers in time to prepare the adequate strategy for meeting the designer's wishes. It will hardly be of interest to carry out calculations in connection with each fire test, but in a number of cases it will be worthwhile, if our fire engineering standards become more detailed.

It is important to emphasize that fire tests will continue to be an indispensable part of fire engineering, especially as there are a number of aspects we are not able to figure out now and hardly will be for many years to come.

As will be seen below the thermal conditions in a furnace are not adequately described by the thermocouple temperature as stated by ISO 834. Actually, it is a matter of knowing

(1) the thermal radiation incident on the structure during the test and

(2) the convective heat transfer components consisting of gas temperature and gas velocity. The construction, its geometry and materials are known to the designer.

Naturally, both (1) and (2) will be functions of the testing perios.

Since temperatures take some time to penetrate into and act on a structure a knowledge of (1) and (2) may also be necessary during a cooling period. According to experience, however, it is sufficient to know the development of the thermocouple temperature, as gas and wall temperatures in the furnace are practically the same during the cooling, except, of course, where a drastic ventilation of the furnace takes place.

Fire-test furnaces

It might be appropriate briefly to point out some facts about the great variety of furnaces characterized as "fire-test furnaces".

First "vertical fire-test furnaces". Even if we look only at furnaces in Europe we find considerable differences as regards size, design, and position of heating device. In some cases also wall materials are different.

Some sketches will support the brief descriptions. Fig. shows a type of furnace in which the distance between the front wall and the back wall is short. There are a large number of burners, usually gas burners. They burn more or less direct towards the structure to be tested, which makes up the front wall.

Where the jets from the burners hit the structure their very high temperature and velocity create a blowpipe effect, which causes a considerably higher degree of convective heat transfer than elsewhere.

Fig. 2 shows another design in which the distance between the front wall and the back wall is much longer and where the burners are mounted on the side walls in an unspecified way; they may, e.g. be placed in staggered rows, etc.

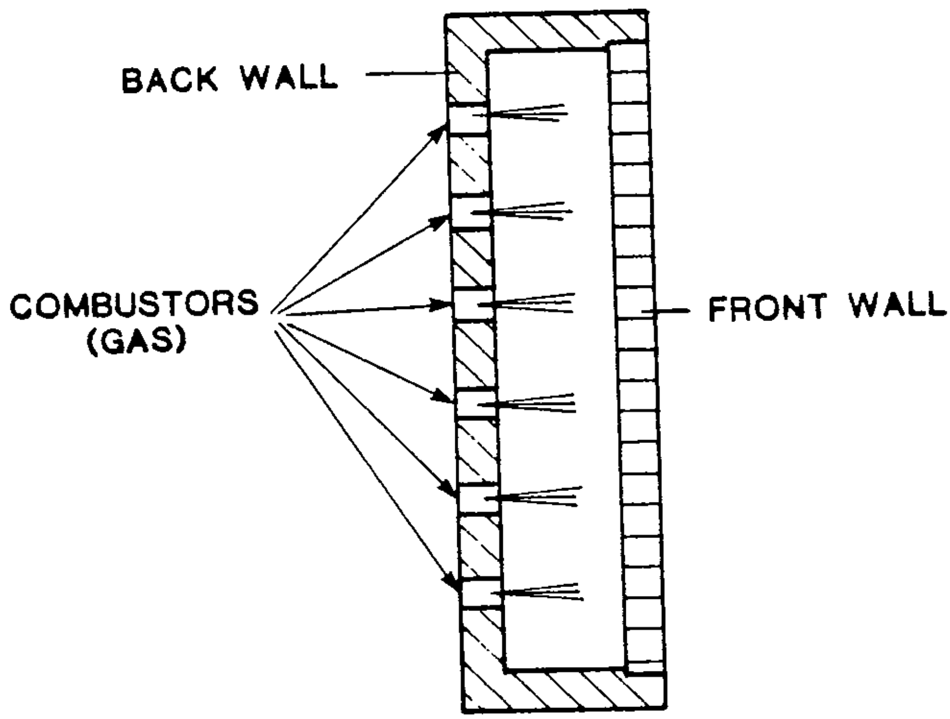

Fig. 1. One type of furnace.

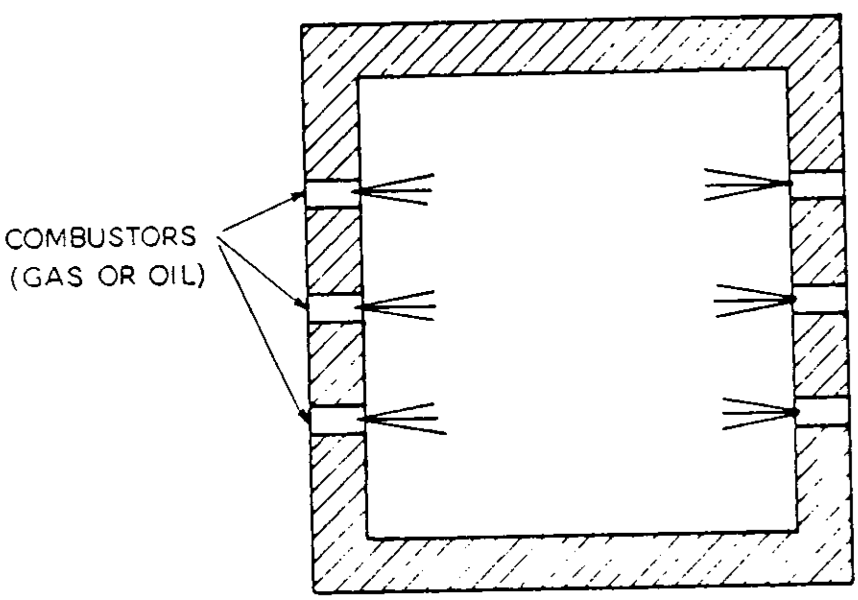

Fig. 2. Another type of furnace.

The burners are fired with oil or gas. The discharge of the combustion products is often effected through a hole at the bottom of the furnace. The placing of the burners on the sidewalls and their spacing are of importance for the flow pattern in the furnace.

In some furnaces it is possible to place a horizontal beam through the middle of the furnace. In some cases a column can be placed in the furnace.

Yet another type of furnace which is specially used for the testing of columns is shown in Fig. 3.

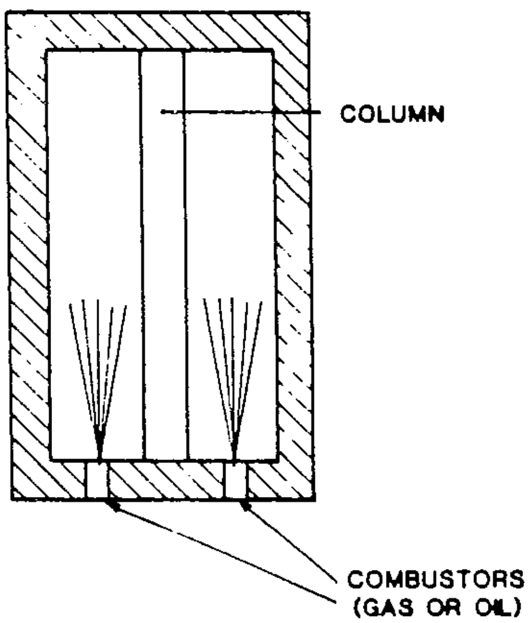

Fig. 3. Furnace for the testing of columns.

In principle, the burners can also be placed in the ceiling of the furnace. The width varies from furnace to furnace and so does, accordingly, the space around the column. In some furnaces the column can be statically loaded.

"Horizontal furnaces" are usually heated by burners placed on the sidewalls, but there are various varieties. In some cases the sectional elevation is large, in others it is small allowing space only for a horizontal beam and a single burner. The large furnaces lend themselves to the testing of floors that are statically loaded, but also other constructions can be tested. The thermal load of large furnaces may be rather different from that of small ones that have only a single burner; in a small furnace the convective heat transfer share of the total heat transfer will be much larger than in a large furnace. See [2].

The aim of this section is merely to remind the reader of the matters mentioned above so as to create a background to what follows, for it must be evident that the thermal influences (1) and (2) may be very different, even if the thermocouple temperature follows the temperature curve of ISO 834.

Are thermocouples always unsuitable for fire engineering purposes?

No, this is far from being the case but, unfortunately, they often will be when applied in fire-test furnaces. This is due to various facts; an essential one is that the combustion products are usually nearly "optically thin", i.e. the thermal radiation (temperature and reflection radiation) from the interior surfaces of a furnace is not reduced very much during its passing through the furnace.

Owing to the symmetric nature of a globe a spherical thermocouple will - irrespective of its diameter - receive the correct incident radiation at the solid angle 4π in such a way that it registers the incident radiation in relation to the solid angles. Consequently, the wording of ISO 834 is particularly unfortunate in that it prescribes a distance of 10 cm from the test wall. This means that the radiation from the test wall constitutes nearly half the total radiation received by the thermocouple and it will thus have an extremely strong influence on the temperature of the thermocouple. Beyond this the thermocouple will receive convective heat transfer.

This is quantified in the equation at the bottom of page 122 [1]. Among other things, this expression contains the convective heat transfer $h(W/(m^2 \cdot K))$. In [1] is shown the definition of h on the basis of one of the equations from the literature. This does not help us very much, however, because a thermocouple is not spherical, one reason being that the two wires - which will often be intertwined - disturb the spherical shape. While the heat transfer number to a globe is independent of the direction of the gas flow the heat transfer number to a thermocouple depends on the direction; this is also the case if the thermocouple is placed in a steratite-tube. Consequently, the convective heat transfer numbers for globes can be used only to obtain a rough idea of the order of magnitude of h for thermocouples.

This is where the globe thermometer gets into the picture having the correct spherical shape and causing only a negligible disturbance by the wires as the diameter of the globe is now several centimetres. We will revert to this.

Resuming the provocation of the heading of this section we will consider the conditions of the thermocouple in a "nearly optically thick" gas. Such combustion products result from a strongly sooting combustion such as that of plastic burning [2], but also other kinds of fire may develop considerable amounts of soot. It is characteristic that in such cases the radiation will not penetrate the combustion products (the gas) but will be absorbed, e.g. 0.5 m in the gas and will thus give off its energy to the gas. This can be established by means of the Monte Carlo method, which makes it possible to trace where the various emitted photon bundles are absorbed. In this case the thermocouple thus only "sees" the combustion products provided it is entirely shrouded in them, and the radiation temperature from the gas is practically equal to the gas temperature, so convection is of minor importance. Thus, if the thermocouple is not covered by too thick a layer of soot and if is is thickly shrouded in combustion products during the entire fire its reading will in this case be nearly correct.

What can be done?

One suggestion has already been made, namely to use a globe thermometer instead of the small thermocouple and to place it in the geometrical centre of the test-fire furnace and not close to the test wall or any other test object. Another suggestion is very simple: raise the temperature of the interior surfaces of the fire-test furnace to a level corresponding to that of the gas temperature; the temperature of the radiation from surfaces will thus differ little from that of the gas. Although the convective heat number is still high and extremely uncertain it will constitute only a small part of the total heat transfer to the thermocouple.

In practice, this can be done by lining the fire-test furnace with Kaerwool or a similar lightweight insulating material only a few centimetres thick. Without interfering with the practical solution we should think that it would be possible to fasten the Kaerwool by pulling out metal clips at certain points. This method was used in the fire-test furnace of the Laboratory of Heating and Air Conditioning without causing any inconvenience.

We now have the advantage of a material in the furnace that easily follows the gas temperature as it behaves "nearly adiabatically" as far as radiation is concerned. At the same time we still have the gastightness, which is an essential advantage of the conventional brick-built furnace, and its sturdiness to materials falling down. It must be possible to carry out this simple and inexpensive adjustment in existing furnaces without great difficulty, the more so as the proposal is not in contravention of ISO 834. Of course, we are aware that such a proposal may meet with opposition in commercial quarters, for a result may be that a construction that was previously approved is now in danger of failing the test.

Even if the above-mentioned simple advice is followed the gas temperature will vary from place to place and so will the thermal radiation, but an appreciable homogenization has taken place. The variations are due to the fact that the temperatures in the combustion zones are higher than the mean value of the gas temperature. Naturally, the flow conditions have an effect, and the instructions to "place the globe thermometer in the geometrical centre of the test-fire furnace" should not be taken so rigorously that the globe is placed direct in a jet.

Still another thing to be included: a better measurement of the thermal effects. This is what we will look at in the following.

Measuring possibilities

The technical solution of thermal measurements in fire-test furnaces is not difficult, as these measuring problems were solved several years ago in connection with investigations of combustion and heat transfer in furnaces. The problem of measuring in fire-test furnaces, however, must be viewed in a somewhat different way, especially where it is a question of determining thermal radiation incident on beams and columns in a furnace, where they are exposed to radiation all way round.

It seems reasonable first to explain how to measure radiation incident on a furnace wall, gas temperatures, and gas velocities in a furnace. This was done in [1]. See also [3].

High-quality measurements

(1) At the solid angle 2π the correct incident radiation can be measured with an accurately constructed and accurately calibrated ellipsoid radiation meter (a conventional radiation meter). The application of this apparatus is outside the scope of ordinary fire testing as it is a very difficult apparatus to handle, and calibration and 2π control are also difficult to carry out.

In the Nordtest investigation we used it the same way it was used in [1], namely as a base apparatus.

(2) The correct gas temperature is measured with a suction pyrometer. An accurate determination of the gas temperature, however, is not a very important parameter for checking on

fire tests, since it has a direct influence only on the convective heat transfer.

(3) Gas velocities in a furnace can be accurately measured with a five-hole globe (a Taylor globe). This parameter is not very important either.

Flux measurements

In practice, flux meters, i.e. meters that measure radiation as well as convection, will have to suffice. In the best of these meters convection constitutes a minor part and they allow a correct consideration of the influence of convection.

(4) Due to its strong and unverifiable convective heat transfer the thermocouple is the poorest of the flux meters, especially when placed in accordance with ISO 834 at a distance of 10 cm from the specimen, where it mainly registers the radiation from the specimen and not, as it ought to, the incident radiation on the specimen.

(5) The globe thermometer is the best flux meter for the determination of the incident radiation at the solid angle 4π as its reading is theoretically correct and the convective contribution is small owing to the large diameter of the globe.

Its spherical shape makes this thermometer independent of the flow direction. Consequently, it is possible to determine the convective contribution. [1] gives a detailed description of the dynamic conditions (Appendix D) and [4] gives more calculation results. An aged thermocouple calibrated by a qualified institute should be used. It is necessary to calibrate only the thermocouple and not the globe itself.

(6) Harmathy suggested the application of a box-shaped meter so as to enable the flux to be measured on four sides (2π each) (Proposal IV). In that case eight thermowires must be led out from the meter.

The convective contribution now depends on the angle of the influx to the meter. This complication as compared with the simple globe thermometer is not necessary. See Fig. 5.

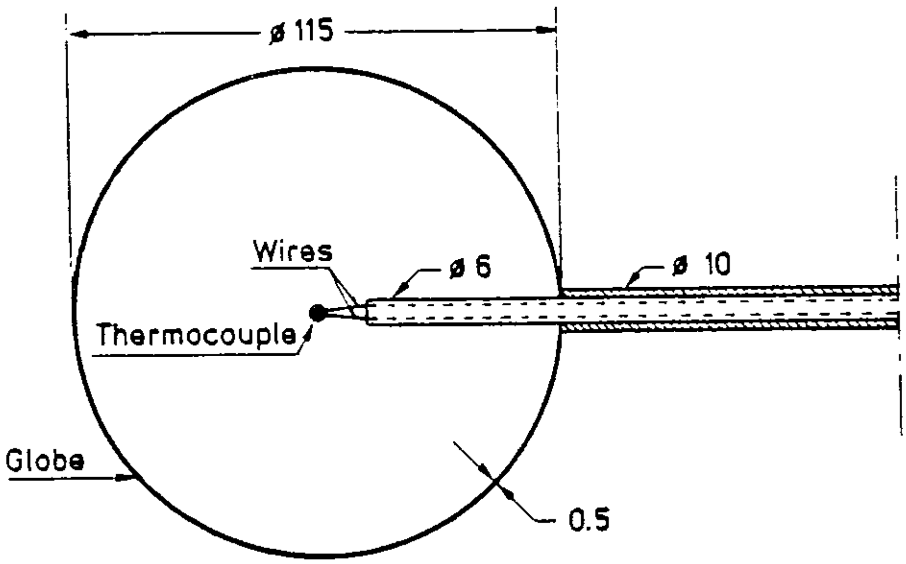

Fig. 4. Globe thermometer [1].

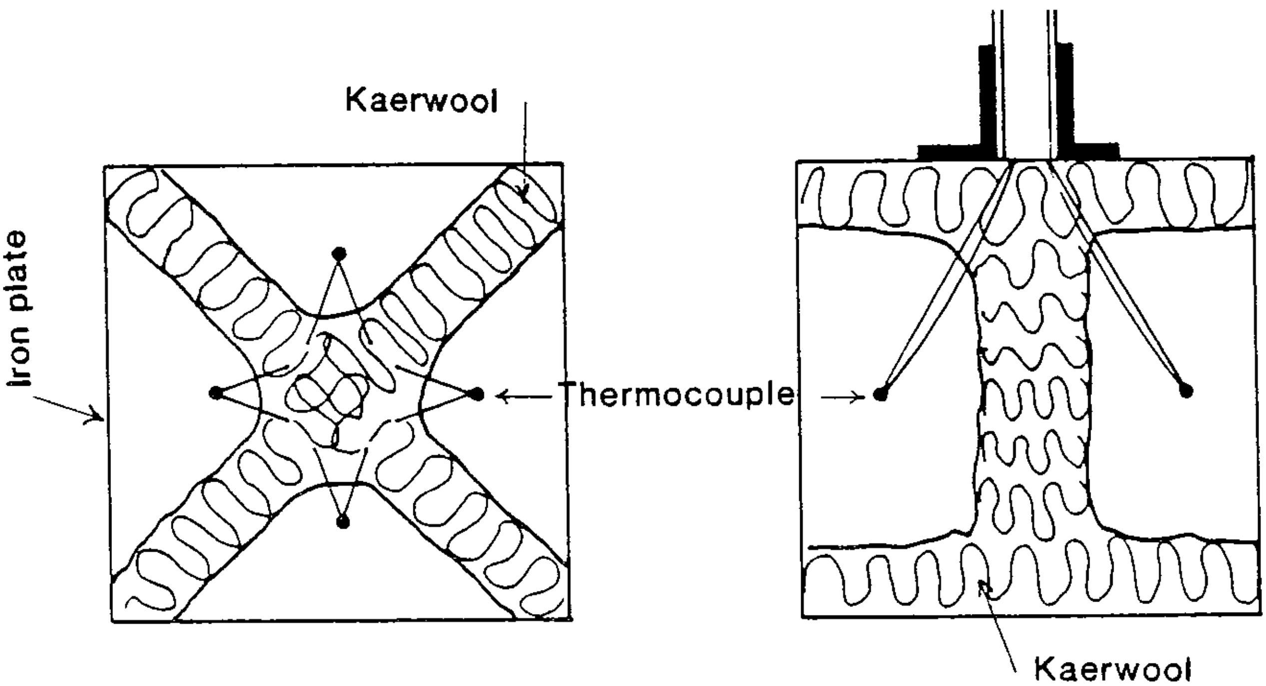

Fig. 5. Box thermometer.

(7) Plate-shaped flux meters were suggested by Wickström and a modified model by Babrauskas [5]. A plate-shaped model was tested at the Laboratory of Heating and Air Conditioning. See Fig. 6.

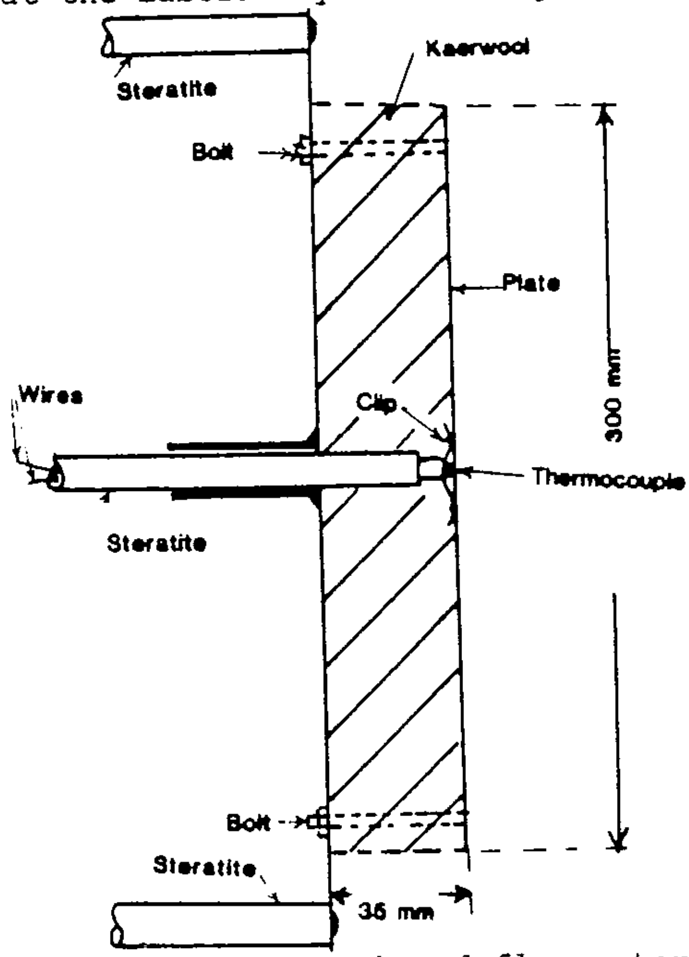

Fig. 6. Plate-shaped flux meter.

As pointed out earlier in this paper an aged and calibrated (at the Risø National Laboratory) thermocouple was used. It was secured by a clip on the back of the plate in which way welding was avoided. The plate is made of stainless steel AISI 347 and measures 30 × 30 cm; behind it there is a 35 mm Kaerwool insulation. The meter is mounted on the front wall. A fair-sized plate was chosen, since it is not possible to calculate the relation between the size of the plate and the convective contribution to the flux. This is due to the fact that the heat transfer is strongly dependent on the flow conditions of the combustion products near the plate. Consequently, calculations on the basis of Nusselt numbers are not applicable, the requirements not being fulfilled. In general, it must be said that the larger size the better.

Upon termination of the experiments the thermocouple was recalibrated at Risø. There was no (less than 1°C) change from the first calibration.

The results of two measuring series are shown in Figs. 7 and 8. The top curve in the figures is the incident radiation in kW/m^2 calculated on the basis of the suction pyrometer temperature T_g with

$$H = \sigma \cdot T_g^4 \quad \left(\frac{W}{m^2}\right)$$

where σ is Stefan-Boltzmann's constant.

The second curve from the top is the incident radiation calculated on the basis of the thermocouple temperature T_t with

$$H = \sigma \cdot T_t^4 \quad \left(\frac{W}{m^2}\right)$$

The third curve shows the incident radiation calculated on the basis of the plate temperature T_p with

$$H = \sigma \cdot T_p^4 \quad \left(\frac{W}{m^2}\right)$$

The curve at the bottom shows the correct incident radiation measured with the ellipsoid meter of the Laboratory of Heating and Air Conditioning.

The values measured during the first period of about five minutes are uncertain and, accordingly, not included.

The thermal inertia is practically the same for the globe thermometer, the plate-shaped meter, and the ellipsoid meter. See [4].

Conclusion

Since the incident radiation on a specimen is the most important parameter as regards the heat transfer to the specimen it is necessary to control the fire-test furnace on the basis of a temperature which reasonably represents thermal

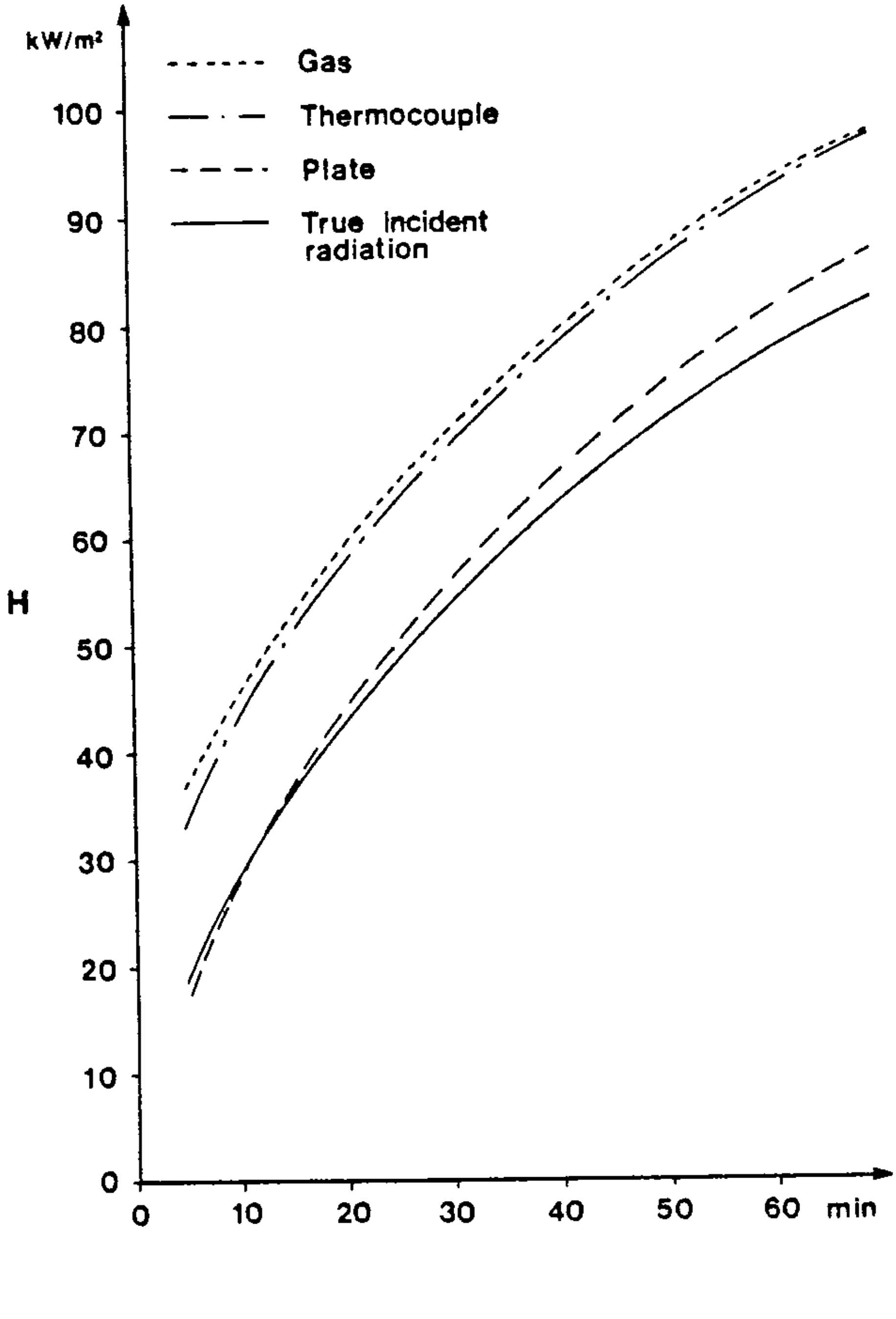

Fig. 7. Comparison of incident radiation determined by a suction pyrometer on the basis of the gas temperature, by a thermocouple (ISO 834), a plate-shaped flux meter, and an ellipsoid radiation meter.

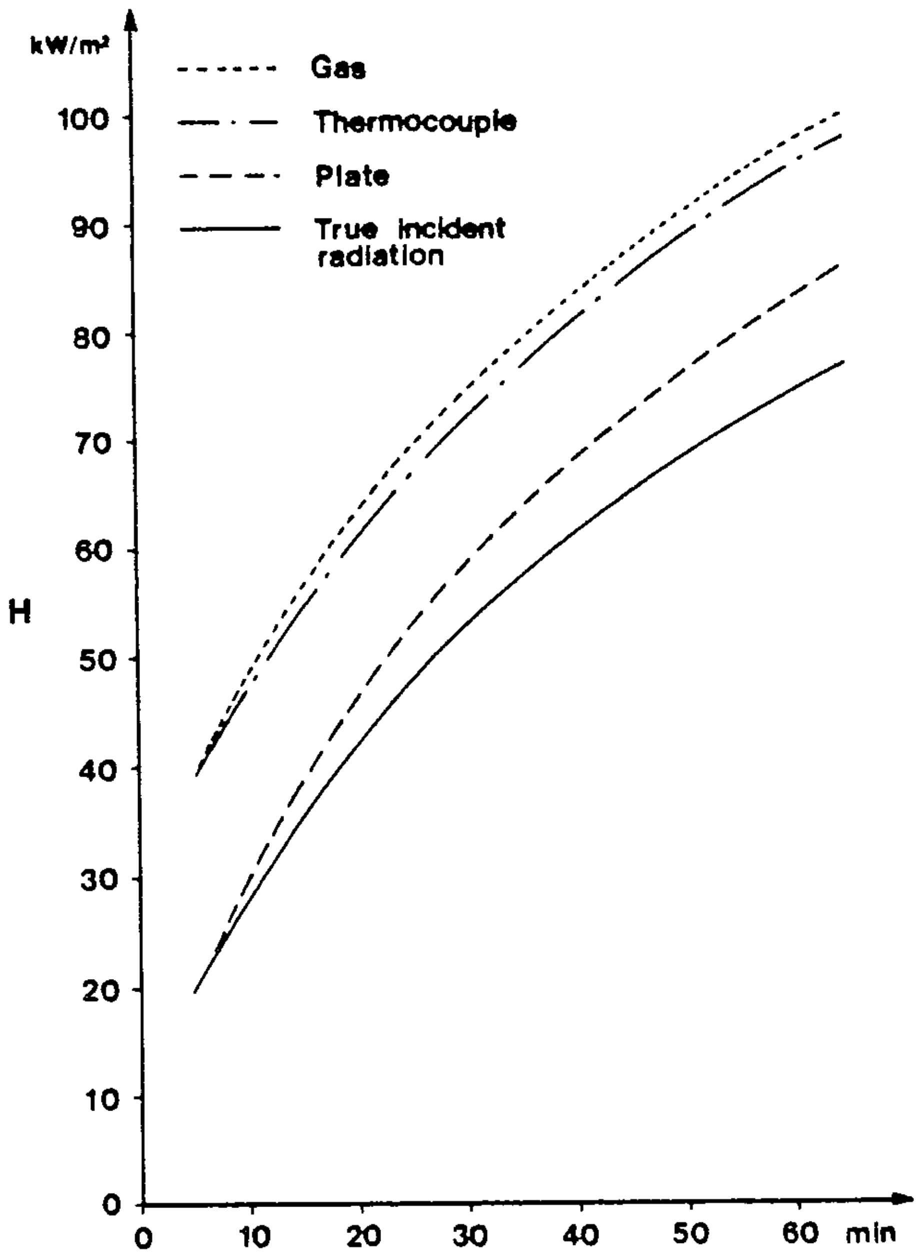

Fig. 8. Comparison of incident radiation determined by a suction pyrometer on the basis of the gas temperature, by a thermocouple (ISO 834), a plate-shaped flux meter, and an ellipsoid radiation meter.

radiation. The globe thermometer reasonably represents this temperature in the case of incident radiation on beams and columns in furnaces, while the plate-shaped flux meter reasonably represents it in the case of incident radiation on the front wall.

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SWEDISH NATIONAL TESTING INSTITUTE
Fire Technology
P.O. Box 857, S-501 15 BORÅS, SWEDEN
Phone +46-33 16 50 00

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