Test Furnace for Radiant Burners

Project Report
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## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>2</td>
</tr>
<tr>
<td>1.1 Objectives for the Test Furnace</td>
<td>2</td>
</tr>
<tr>
<td>2 Overall Design</td>
<td>4</td>
</tr>
<tr>
<td>2.1 The Furnace Frame</td>
<td>6</td>
</tr>
<tr>
<td>2.2 The Wall Panels</td>
<td>9</td>
</tr>
<tr>
<td>2.2.1 Burner Panel</td>
<td>10</td>
</tr>
<tr>
<td>2.2.2 Load Insertion and Exhaust exit Panel</td>
<td>12</td>
</tr>
<tr>
<td>2.3 Chimney</td>
<td>13</td>
</tr>
<tr>
<td>2.4 The measuring bridge</td>
<td>15</td>
</tr>
<tr>
<td>3 Flow Control System</td>
<td>17</td>
</tr>
<tr>
<td>3.1 Cooling system</td>
<td>17</td>
</tr>
<tr>
<td>3.2 Premixed Combustion Air and Gas</td>
<td>20</td>
</tr>
<tr>
<td>3.3 Flue Gas</td>
<td>20</td>
</tr>
<tr>
<td>4 Instrumentation</td>
<td>22</td>
</tr>
<tr>
<td>4.1 Primary Instrumentation</td>
<td>22</td>
</tr>
<tr>
<td>4.2 Secondary Instrumentation</td>
<td>24</td>
</tr>
<tr>
<td>4.3 Control Instrumentation</td>
<td>26</td>
</tr>
<tr>
<td>5 Experimental Procedure</td>
<td>28</td>
</tr>
<tr>
<td>6 Conclusion</td>
<td>30</td>
</tr>
<tr>
<td>7 References</td>
<td>31</td>
</tr>
</tbody>
</table>
1 Introduction

This report gives a detailed description of the test furnace previously described in ref. /2/. The test furnace was designed for the purpose of performing indirect efficiency measurement of porous radiant burners. The test furnace was developed as part of the SERB project. The objective of the project is to develop selective emittance burners. In order to verify the improved efficiency, the test furnace was developed.

1.1 Objectives for the Test Furnace

The test furnace is to provide: data for performance evaluation of selective emittance radiant burners, and data for verification and adjustment of mathematical models of the radiative and convective heat transfer. The objective of the test furnace is to perform comparative measurements of Porous Radiant Burners (PRB), in order to estimate the degree of flux matching between the PRB and the load, see ref. /2/.

As previously described in ref. /2/, the possible uses of selective emittance radiant burners are numerous. The number of test cases has, therefore, initially been limited to paper and paint because of the extensive reference material.

It was decided to evaluate the performance of the selective emittance radiant burner by the mass change rate of the load in case of paper drying, and by the temperature change rate of painted loads. An improved energy transfer between burner and load will result in a higher evaporation rate / faster heating of the load. In order to compare the measurements of several PRB’s directly, the measurement conditions must be identical for all tests. This means that furnace temperature, cooling water flow, etc., must be controlled within a small margin.

In order to provide data for the mathematical models, additional data had to be obtained: temperatures on furnace walls, flue gas temperature, mass flow of flue gas, and flue gas composition.
When the test furnace was developed, it was borne in mind that the test furnace in years to come shall function as a general purpose test furnace for radiative heat transfer. Thus, the design was made as flexible as possible.
2 Overall Design

In this chapter the overall design of the test furnace will be presented, and in the following sections a more detailed description of the parts will be given.

It was decided that the test facility should consist of a closed furnace. The reason for choosing a closed furnace was the need to control and measure the temperatures of the various surfaces that could influence the load. A closed furnace allows measurement and control of all surface temperatures and thereby the radiation inside the furnace. This eliminates possible error sources. An open furnace design would cause dilution of the flue gases, which would lead to an unknown moisture content in the furnace gas around the load and unreliable measurements of burner emissions. The exhaust exit is controlled in order to maintain a constant furnace atmosphere. Two different exhaust exit configurations are used: a closed furnace configuration where the flue gas is led out of the furnace through a chimney, and an air sheet configuration where the flue gas is flushed away from the surface of the burner. The furnace has two principle modes of operation: closed and open furnace.

It was decided that the test furnace should consist of three cubic elements of 1x1x1 m, giving a rectangular furnace of the dimensions 3x1x1. These dimensions were chosen in order to give a simple geometry that could easily be adapted for a mathematical model. The large furnace volume causes the velocities inside the furnace to decrease, as the cross sectional area insures low velocities and damping of the flow. This is important as it is desirable to have as low as possible convective influence of the furnace gas on the load.

The fundamental layout of the test furnace is shown in Figure 1.

Figure 1. Basic layout of the test furnace.
The furnace walls may be divided into 14 elements or panels of 1x1 m. The walls are the system boundaries. The boundary conditions were considered from two angles: as the thermal boundary and as the radiation boundary.

There are two thermal boundary conditions: constant heat flux and constant temperature. The constant temperature may be obtained by cooling or heating the furnace walls to a chosen temperature. The heat flux condition is most easily met by choosing zero heat flux: insulated walls. The two basic wall thermal conditions are seen in Figure 2.

![Figure 2. Dual purpose furnace walls: adiabatic and constant temperature.](image)

The radiation wall condition could consist of a surface with a known emission spectra. Two conditions seem interesting: the black totally absorbing wall, and the white or polished totally reflecting wall. In connection with the two thermal boundary conditions, the black wall is interesting in combination with the fixed temperature condition, and the reflecting wall is interesting combined with the insulated hot wall. The cold black wall will absorb all radiation inside the furnace, and leave the radiation exchange from the PRB as the most important source of radiation to the load. The cold walls were painted with a high temperature resistant black paint and the hot walls were made of a polished aluminium plate. The absorption spectra of the black paint and the polished aluminium were measured by ECN, and are shown in Figure 3.
Figure 3. Wall absorption spectra for black high temperature paint and polished aluminium measured by ECN.

In order to make the test furnace flexible, the walls panels can be moved around to different locations in the furnace. This has made it possible to alter the test conditions and use the test furnace for several different types of measurements.

The burner is placed in a specially adapted wall panel. As the panels can be placed at different locations in the furnace walls, the design offers many possibilities for testing. Initially, the burner was placed in the centre of the panel.

A top panel was designed for the purpose of removing flue gas from the furnace and to allow for the insertion of a load into furnace.

2.1 The Furnace Frame

To provide support for the panels, a frame has been constructed. The frame was designed in such a way that only the panels would be visible from the interior of the furnace. The placing of the panels in the frame is shown in Figure 4.
The design shown in Figure 4 has a thermal bridge where the panels are mounted on the frame. It was considered to be too complex to eliminate and it was permitted in the design.

The standard element for the frame is stainless steel (AISI 304) cubic pipe in the dimensions 60x60x3 mm. The choice of stainless steel for the frame was justified by the possible formation of condensed water during start and stop. Stainless steel was preferred for the frame instead of painted iron, due to the heat load on the frame which would result in damaged paint.

The test furnace had to be lifted off the ground, because there is a need to service the bottom panels and because of the cooling water pipes sticking out of the test furnace. In addition to the four corner supports of the frame, it was found necessary to add extra supports under the frame due to the expected displacement caused by the mechanical load of the water filled panels. As a consequence, additional supports were placed at each assembling point of two panels, see Figure 5.

The water connections and the mechanical connections between the frame and the panels were made through holes in the frame. The mechanical connection between the frame and the panel was made with M10 bolts.

The final frame design is shown in Figure 5.
The beam placed horizontally beneath the burner support the pneumatic cylinders used to raise the measurement bridge, and for fixing the burners.

The final test furnace is seen in Figure 6:
2.2 The Wall Panels

The walls needed to provide two sets of boundary conditions. The cold walls need a supply of cooling water while the insulated walls do not need any external cooling or heating. The cooling water connection is made through the frame. As the frame had been welded, it was expected that the accuracy of the frame would demand that the walls could only be placed with a significant effort. This means that it is somewhat difficult to remove or replace the wall panels without significant work effort. Therefore, it was decided that the wall sections should stay in the frame, and only be removed when another type of panel would be needed. The insulated wall condition was provided by insulating the interior of the furnace. The furnace volume diminishes but not to a severe degree.

To protect the water filled panels from corrosion, stainless steel (AISI 304) was chosen for the water compartment. The hot part of the sandwich was made of a ceramic fibre plate on which was glued a 1 mm aluminium plate. During the experiments, the aluminium plate will oxidise, which will cause a reduction of the reflection.

![Figure 7. Panel design.](image)

The water compartment was made of a rectangular frame of U-profiles of 1x1 m. On the frame was welded a 2 mm stainless steel plate on each side, creating the water compartment. To prevent the water from running from inlet to outlet in a straight line, thus creating a bad temperature distribution, the water compartment was divided with four baffle plates. The baffle plates also increased the stiffness of the construction. The panel design is shown in Figure 7.
The 2 mm steel plates were welded along the edges and spot welded through holes at the baffles. The stress induced by the welding would deform the wall panels and, therefore, a low heat input welding method, TIG, was chosen. In addition, the welding zone was cooled during the process. The final panels dimensions are within a few millimetres accuracy, which is sufficient for the purpose.

There are two different types of connections between the frame and the panel: a water connection and a mechanical connection. In order to ensure good connection, both the water connection and the mechanical connections are made in the panels’ U-profile.

The dimensions chosen for the panel frame U-profile were 30x15x4 mm which did not allow cutting thread into the panel frame. An alternative solution was chosen where a cap nut and a socket were welded on the U-profile from the outside for the mechanical and water connections, see Figure 8.

![Figure 8. Arrangement for bolt and water connections.](image)

2.2.1 Burner Panel

A couple of panels were modified for the burner, the exhaust exit and for the load insertion. In the burner panel, an opening for the burner of the dimension 403x303 was made. In order to provide sufficient cooling around the burner, the baffles were rearranged around the hole for the burner.

A hole for the flue gas sonde and a hole for the spark ignition are drilled into the burner panel. The flue gas sonde is placed in the panel because of the possible oxygen diffusion in the boundary layer, which may occur when the sonde is inserted through the stack.
The burner panel design is shown in Figure 9.

The furnace was used with two different burner panels. A panel was modified for air sheet removal of the flue gases. An opening above and under the burner was made, for the purpose of blowing the hot flue gases away. The design of the air sheet burner panel is seen in Figure 10.
Figure 11. Burner panel with air sheet.

Through the burner opening in Figure 10 the air sheet air distribution pipe is seen. The air is blown through the holes onto the curved plate, which directs the air parallel to the burner surface. The holes are covered with a metal mesh in order to obtain a more even distribution of the air in the air sheet. An opening in the full burner length is in the top (not seen because of flow intake). A schematic drawing of the air sheet burner panel is seen in Figure 11. The hole to the right of the burner is used for ignition.

2.2.2 Load Insertion and Exhaust exit Panel

Load insertion and exhaust exit are placed in the same panel. The load used are sheets of paper or metal. The opening in the panel for the load insertion is, therefore, only required to be a few millimetres wide but nearly the full panel length. The largest load to be inserted into the furnace was of A2 paper size (416x590 mm). The opening for the load in the middle of the top panel was set to 650x50 mm parallel with the burner. The mechanism for insertion of the load and instruments for measurement of weight and temperature will be placed on a bridge over the top panel. The measurement bridge is described in section 2.4.

When the flue gas leaves the burner, buoyancy will drive the gas up towards the top panel. The hot flue gases are sucked away outside the panel. The test furnace must provide an option for dual burner operation, which means that there must be exhaust exits on both sides of the mid-top panel. In order to
make room for the suction device along with the measurement bridge, the exhaust exits are divided into two openings for each burner.

The final top panel design is shown in Figure 12.

![Figure 12. The mid top panel for load insertion and exhaust exit.](image)

### 2.3 Chimney

During the experiments, a problem with the oxygen level in the furnace arose. The oxygen level was too high. An analyse of the problem revealed that the exhaust exit area in the mid-top panel was too large. In the centre of the exhaust exit, the flue gas was going up but in the corners of the exhaust exit air was drawn down into furnace. This meant that the furnace gas was diluted, and oxygen levels in the furnace became high. For the flue gas analysis, gas samples was taken 15 mm above the burner which gave correct \( \text{O}_2 \) and \( \text{CO}_2 \) levels but incorrect levels of CO. When the flue gas sonde was moved away from the burner surface, the increased \( \text{O}_2 \) level was revealed. In order to prevent air from being drawn down into the furnace, a stack was mounted on the exhaust exit. The stack entrance is dimension 200 x 50 mm, which means that a part of the exhaust exit in the mid-top panel had to be blocked. A diffuser connects the exhaust exit in the panel with a D105 mm stainless steel tube. A flue gas sonde was placed in the stack one diameter before the exit.
The chimney is seen in Figure 13.

![Figure 13. The chimney.](image)

Flue gas temperature and samples for analysis are obtained with a suction pyrometer in the chimney. The pyrometer reaches into the centre of the chimney. To insure a correct flue gas temperature at the measuring point, the chimney was insulated as seen in Figure 13.

![Figure 14. Flue gas suction from the air sheet configuration of the test furnace.](image)
With the air sheet, the flue gas was sucked away above the burner. The laboratory ventilation system was used to suck the flue gases away. The air sheet chimney is seen in Figure 14.

The blower and the distribution tube for the air sheet are seen in the bottom of Figure 14.

2.4 The measuring bridge

The function of the measuring bridge is: to provide swift insertion and extraction of a load. The insertion and extraction of the loads are maintained by two pneumatic cylinders. The bridge itself is a 30x15x4 mm stainless steel U-profile beam. At the centre of the bridge is a platform for thermocouples. The load of the bridge is placed on the furnace frame. This leads to the usage of two pneumatic cylinders placed on the furnace frame in each side of the furnace.

When the load is lowered into the furnace, it must take place very swiftly. The operator of the test furnace should be able to fix the load while it is hanging over the furnace, and then lower it into the furnace. This requires that the load hangs free above the furnace. The maximum load size is A2 (416x590 mm). The load is hanging in the middle of the furnace. This means that 208 mm of the load is below the middle of the furnace and that there is 500 mm from the middle of furnace to the top panel. The total lifting length is 416/2 mm + 500 mm + 60 mm + a little space = 800 mm.

The mechanical load placed on the pneumatic cylinders is low - only a few kilograms. This led to the choice of the smallest pneumatic cylinder available (D32 mm). The cylinders chosen are double functioning thus giving the required fast movement in both directions. Because of economic considerations, the pneumatic cylinders chosen were without positioning control, which means that there is a risk that the bridge will tilt a few degrees while moving. It was possible to eliminate most of the tilt by calibration of the cylinders and maintaining a good lubrication of the cylinders.

The slit in the mid-top panel for load insertion must be closed during operation. A metal plate is used for that purpose. It was not possible to provide
the correct cold wall condition at the face of the plug due to the practical problems that would arise.

The final construction of the measurement bridge is seen in Figure 15.

Figure 15. Picture of the measurement bridge with polished aluminium load.
3 Flow Control System

In this chapter, a brief description will be given of flow control and flow measuring system designed for the test furnace.

The flow of different fluids in and out of the test furnace must be controlled. For that purpose a flow control system has been designed. The flow of premixed combustion air and natural gas as well as the flow of cooling water through each panel must be known.

3.1 Cooling system

In order to preserve an even temperature distribution on the interior of the furnace during operation, the flow through each panel is controlled individually. At each panel, are placed a manual valve for trimming the flow and a flow meter. The temperature difference across each panel should be constant, which is ensured by measuring the temperature after each panel. The temperature before all the panels is measured at a point upstream. The piping diagram for the panels is shown in Figure 16.

The temperature of the cooling water for the panels must be controlled within a margin. In order to prevent formation of condensed water on the walls, the temperature of the cold furnace walls should always be above the dew-point (59.7°C for Danish natural gas at stoichiometric combustion). Heat is removed from the panels during normal operation, but during start.
and under special conditions, heat is needed to maintain a furnace wall temperature above the dew-point. A gas boiler was, therefore, installed in the cooling water circulation. The excess heat was removed in the cooling tower. The piping diagram for the test furnace is shown in Figure 17.

![Piping diagram for the test furnace.](image)

**Figure 17. Piping diagram for the test furnace.**

E: Gas boiler, MAXOL homewarm 600, 7 kW
F: Flowmeter ISS 10VP
P: Pump, Grundfos UPT 40-60
V1: Danfoss type AVTA
V2: TA-valve Stad 25
V3: TA-valve Lo 2.36 and TRIM A
T: Thermocouple type K.

The heat input from the PRB into the furnace is at design conditions 40 kW. The maximum acceptable temperature rise in the cooling water is set to 5°C. If the situation where all heat is removed by the cooling system is taken as worst case, the mass flow of water through the cooling system is:

\[
m = \frac{P_{PRB}}{c_p \Delta T_{water}} = \frac{40.0 \text{ kW}}{4.2 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}} = 1.9 \left[ \frac{\text{kg}}{s} \right]
\]

The mass flow of water led to the choice of 2" pipes for the main cooling water pipes and 1/2" pipe for the panel connection giving maximum water velocities of 1.4 m/s in main and 2 m/s in panel connection. The total pres-
sure loss should not exceed 1 bar in the cooling system with these pipe dimensions.
Cooling water from the tower was added to the system in a rate that insures a forward circulation temperature of 60°C. For this purpose, a capillary pressure controlled valve was placed in the cooling tower circulation, see Figure 17.

The cooling system is seen in Figure 18.

![Figure 18. Test furnace seen from the end. In the bottom of the picture, the circulation pump is seen. In the top of the picture, the flow meter is seen. The distribution system in the bottom is the forward flow, and return flow is in the top.](image-url)
3.2 Premixed Combustion Air and Gas

The premixed combustion air and gas is delivered by the DGC premixer which enables flow control and data logging of the combustion air and gas flow. The premixer is shown in Figure 19.

![Figure 19. DGC premixer for air and N-gas.](image)

F1: Sharp edge orifice plate (DIN 1952), large D=54.50 mm, d=31.28 mm; small D=27.00 mm, d=16.04 mm.
F2: Gas flow meter, rota type (Krom Schröder)
T: Pt-100 thermoelement
V1: Pressure controlled expansion valve type GBF 40
V2: Pressure controlled expansion valve type GBF 15
V3: Pressure controlled valve type GI 15
M: Air and gas mixer type Stordy MGM 10

3.3 Flue Gas

The flue gas is sucked away just outside the furnace. An opening between the furnace and the suction device was made to secure a pressure larger than the surrounding atmosphere inside the furnace and not some pressure induced by the suction device.
The flow of flue gas can be calculated from the amount of combustion air and gas entering the burner. The mass evaporated from the paper load has an insignificant influence on the mass flow of flue gas.

The sonde for flue gas analysis was placed in the burner panel and in the stack. The flue gas sonde in the stack gave the fastest response to changes due to the placement, while the flue gas sonde in the panel has quite a long dead time (more than 300 sec). The sonde in the burner panel was used for indication of a furnace atmosphere composition. The air in the furnace will after a while be replaced with flue gas.
4 Instrumentation

In the following chapter the instrumentation of the test furnace will be described. The instrumentation has been divided into three categories.

2. System parameters such as wall temperatures, gas temperature, etc.
3. Control instrumentation, eg. panel outlet temperature.

4.1 Primary Instrumentation

The test furnace is designed for paper and paint loads. The procedure for a paper load is: the load is placed in a holder and lowered into the hot furnace. The paper holder is connected with the weight through a thin steel tube. The maximum paper load will be A2 size or 0.25 m$^2$. The paper used will be of various qualities, but for the purpose of estimating the weight of the wet paper, paper of 100 gr/m$^2$ was chosen. The maximum load moisture content was estimated to be 100% of the dry weight. The maximum expected weight of a load was 50 gr. The paper holder holds the paper load straight and aligned with the burners. The holder is connected with the exterior of the furnace through two holes in the top plug. If only one hole had been used for the connection with the weight outside, the load would probably start to revolve and most certainly become unaligned.

The scale chosen is an Ohaus GT-410. The scale has a capacity of 410 g and a precision of 1 mg. The weight can be controlled from a PC through a RS 232 interface. The GT-410 has a total stabilisation time of 2 seconds, which means that right after load insertion the results from the scale will be unreliable for a short while. During the experiments, it turned out that long stabilisation time only was required for re-zeroing. The mass of the load will always vary and it is, therefore, not possible to obtain a total stable input to the scale. This means that the uncertainty of the scale is larger than 1 mg, probably around 10 mg. The scale is re-zeroed when the mass of the paper holder is placed on the scale. This means that only the mass of load and water will be registered by the scale. A typical drying curve is seen in Figure 20.
From the paint loads are obtained temperatures at a number of points on the load during the test. Thermocouples can be soldered onto a metal plate or be placed in holes. The metal plate will be painted on the side facing the burner. In order to ensure a uniform temperature distribution inside the metal plate, a material with a high thermal conductivity should be chosen, e.g. copper or aluminium. For this case aluminium plates have been chosen.

Model results show that the heating rate of the paint load will vary locally along the surface. This is caused by differences in heat flux to the load and by the convective cooling of the load, see ref. /1/. In order to obtain experimental data which may confirm these models, the loads are fitted with two thermocouples. The thermocouples are placed as indicated in Figure 21.

The temperatures are logged directly with the datalogger. The thermocouples used for the load are type K.

Figure 20. Paper drying with SiC burner.

Figure 21. Location of thermo couples on painted load.
Heating of the loads will take place immediately after load insertion. The heating period may be as short as a few hundred seconds. Therefore, the sampling time of the thermocouples should be around 1.0 sec. The heating curves for three different burners are shown in Figure 22.

![Typical heating curves obtained with the SERB test furnace. The heating of a black aluminium plate with three different burners is shown.](image)

**4.2 Secondary Instrumentation**

The objective of the secondary is to obtain the energy balance of the test furnace. As a part of the energy balance measurements, the flue gas composition and temperature will be measured.

The energy balance is obtained by measuring the enthalpy flow into the furnace and out of the furnace. The enthalpy flow into the test furnace is composed by three components:

- Fuel
- Combustion air
- Cooling water

Fuel and the combustion air are accounted for in the pre-mixer. The pre-mixer is coupled directly to the data logger. The cooling water flow is measured and logged continuously. The temperature of the cooling water is measured before the test furnace.
The enthalpy flow out of the furnace is determined by:

- Flue gas
- Cooling water

The enthalpy of the flue gas depends on the flue gas composition and temperature. Gas samples for flue gas analysis are taken above the burner. The flue gas measurements include:

- O₂
- CO₂
- CO
- NOₓ

In the case where the paper load is used, the dew-point temperature in the stack will be measured, as the expected evaporation rate will cause a measurable increase of the water content in the flue gas (6-9% vol. constituted by water ref. /1/).

The cooling water temperature may be measured after each panel as described in section 3.1. The temperature difference over each panel should be the same.

The energy equation for the test furnace at stable conditions is:

\[ m_w c_{p,w} T_{\text{forward},w} + m_a c_{p,a} T_a + m_g c_{p,g} T_g + \Delta H_g m_g = m_{fg} c_{p,fg} T_{fg} + m_w c_{p,w} T_{\text{return},w} \]

The heat capacity of the flue gas is dependent on the excess air number and flue gas temperature. The experiments were performed with the excess air number at \( \lambda = 1.05 \) and \( \lambda = 1.1 \). The mean heat capacity calculated on the basis of the Sandia data base is shown in Figure 23.
Figure 23 Specific mean heat capacity for flue gas of complete combustion of Danish natural gas.

The temperature measurements are performed with type K thermocouples apart from the natural gas temperature $T_g$ and the combustion air temperature $T_a$ which are measured with Pt-100 thermoelements.

### 4.3 Control Instrumentation

The objective of the tertiary control instrumentation is to supply data for the safety system of the test furnace, and data at points in the furnace which are not directly related to the primary objective. This data is needed for comparison of model and experiment.

The wall temperatures may not exceed approximately $500^\circ C$ when the hot side of the panels is used. The hot side of the panels is made with an aluminium plate on top. The melting point for aluminium is $636^\circ C$, but the aluminium becomes very soft at temperatures higher than $500^\circ C$. The wall temperature check point is placed on the burner panel.

The flow through each panel may be measured manually. Each panel is equipped with an orifice plate valve. The pressure drop over the orifice plate is measured with a syringe type of pressure gauge. The syringes, there is one for high pressure and one for low pressure, are inserted through a rubber material before and after the orifice plate. The manometer is connected with
a computer, which has the necessary information (Kv coefficients) to calculate the flow. The manometer is a TA-CBI.

The flow through the panels is needed for model comparison as the actual heat flux into each panel should be known, in order to compare it with the numerical results.

The burner is monitored with a two colour pyrometer. The pyrometer is placed outside the furnace, and pointing towards the burner in 45° angle. An inspection glass is used to obtain light samples from the burner. The two colour pyrometer is operating at 0.88 micron and 1.05 micron well outside the water band at 2.7 micron. The range is from 670°C to 1170°C.
5 Experimental Procedure

When the furnace is started a procedure must be used in order to prevent condensation of water inside the furnace. The circulation pump is started, and it is ensured that there is a flow through each panel and that there are no leaks. The gas boiler is switched on. After approx. 1.5 hours of heating, the temperature of the wall panels has reached the operating temperature 60°C. Because of the required heating time, the heating must be started a few hours before the planned experiments. If the PRB is used for heating the furnace, the capillary valve (V1 in Figure 17) must be turned down to an opening temperature around the ambient temperature. Otherwise, the valve will shut off the cooling water circulation, which leads to boiling in the burner panel and in the mid-top panel before the valve opens. As the cooling water system is closed, the formation of steam bubbles may damage the wall panels.

The gas inside the furnace must be replaced with flue gas before the experiments starts. In the model, a furnace atmosphere composed by pure flue gas is used. After the furnace is started, the flue gas sonde placed in the stack is moved down to the burner panel. When the oxygen level measured in the burner panel is the same as the oxygen level in the stack, the experiments may be started. The required time for replacing the air in the furnace with flue gas is around 30 min.

All the trimming valves are open when the test furnace starts. Once the test furnace is stable, the temperature is measured after each panel. Some panels will need a higher flow to ensure the same temperature difference, while other panels will need a lower flow. The flows through the panels are adjusted with the trimming valves. When a stable condition has been reached, the flow through each panel was measured, and the enthalpy change in the panels found.

Burners can easily be replaced. The opening in the burner panel is just adequate for the burner(s). When the burners are in place, they are fixed to the frame. Aluminium tape is used for sealing around and between the burners. The pressure drop is not equal for all the burners. Therefore, the flow of premixed air and natural gas is dependent on the actual burner type, and the
setting of the pre-mixer must be adjusted for each new burner(s). The pressure drop across the mixer secures that the excess air ratio is equal for all the tested burner types. The burners are ignited with a pilot flame or a spark. The pilot flame is the safest method as the spark often fails to ignite the premix due to limited excess air interval where the premix can be spark ignited. The mixer is adjusted to an excess air ratio of $\lambda=1.05$.

The aluminium plate load was a 5 mm thick A2 size (590x416 mm). The measurement bridge was hoisted and the load was attached with two chains. Before the thermocouples were placed in the load as indicated in Figure 21, the holes in the load were filled with a heat conductivity enhancing silicone paste. The heat conducting silicone paste was applied in order to reduce dead time of the thermocouples.

To ensure correct optical properties, the hot wall aluminium plates must frequently be inspected during the experiment. If the optical properties have been altered, the plates must be re-polished.

The data acquisition computer program was restarted, and the load was lowered into the furnace. By monitoring the load temperature, it is possible to determine when the load has reached equilibrium temperature. The test is finished when the equilibrium temperature is reached and the load is hoisted out of the furnace. A metal plate is used to cover the opening in the test furnace. The load may be removed and replaced with a new.

The paper load requires that water is added to the paper before it is lowered into the furnace. The paper samples are placed submerged in a water tank. The sample is taken from the tank and placed in the holder. The paper is able to absorb water about 1.5 times the dry mass. Afterwards, the load is lowered into the furnace. After a while in the furnace, the paper dries out.
6 Conclusion

A test furnace for radiant burners has been constructed. The furnace is able to measure the performance of different kinds of burners by the rate of heating and drying. In order to control the energy flow in the furnace a measuring system has been designed.

The test furnace may be used for testing a wide range of radiant burner applications. This is insured by two different furnace wall conditions: cold absorbing and the hot reflecting wall along with the closed furnace and the air sheet configuration of the furnace.

During the experiments a number of modifications were made to the furnace. The furnace concept has been improved to make start up time shorter as the furnace wall may be pre-heated. The sample insertion routine has been optimised in order to save time, with easy access and swift insertion and extraction of the sample.

Tests have shown a good reproducibility of the experiments. Surveillance of furnace temperatures and flue gas composition insured that the reason for any differences could be resolved.
7 References
