A LINING MANAGEMENT SYSTEM FOR SUBMERGED ARC FURNACES

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ABSTRACT

What is not measured cannot be managed. This is true of most things, including a furnace lining. This paper describes a Lining Management System used for this purpose. It provides the operations staff with a management tool to predict long term lining life and acts as a process optimisation tool. It alarms and records upset furnace conditions. Outputs from the system are described as presented through a specially developed software package and interface. It includes vertical and horizontal furnace sections showing estimated isotherms through the lining as well as the furnace bath. It also shows calculated heat flux values, estimated lining wear and the freeze layer profile. A novel three-dimensional display is described which provides the operator with a big picture view of the furnace crucible profile under real time operating conditions. The powerful trending facility for analysing both measured and calculated values is discussed. The required instrumentation hardware as well as the installation thereof is described, with special reference to an electrically insulating thermocouple socket design. Finally feedback is provided on the first year's performance of the system installed on an open ferrochrome furnace at Assmang Chrome, Machadodorp, South Africa.

1. INTRODUCTION

Rebuilds of submerged arc furnaces are necessary to replace old equipment and to bring about enhancements to the furnace and to replace the refractories. It is common practice to operate furnaces at absolute maximum capacity during high demand periods. When a furnace burn-through occurs during these times, the resulting loss of production has an adverse effect on the income of the producers. It is therefore important for furnace operators to measure and understand the effect of their operating practice on lining wear. A system that can do this will allow them to estimate and manage the lining life.

Pyromet Technologies was given the opportunity to develop and implement such a system at the Assmang Machadodorp ferrochrome plant on their no. 2 furnace during a recent rebuild. This paper discusses the system in more detail, and looks at its first year of operation.

Firstly the heat transfer calculations and algorithms used in the Lining Management System are discussed. The furnace lining arrangement is discussed indicating the relative positions at which the thermocouples are spaced along the shell. The points covered under the hardware are the electrical insulation of the thermocouples and thermo wells, and the PLC plus standalone PC. Next the Lining Management system itself is reviewed, describing the user interface and the setup of the system. Finally feedback is provided for the first year of operation on Furnace no.2 at Assmang's ferrochrome plant at Machadodorp, South Africa.

2. HEAT TRANSFER CALCULATIONS

The Lining Management System calculations for estimating refractory lining wear and freeze lining thickness is based on Fourier's Law for heat conduction through solid bodies [1]. For the furnace hearth calculations the linear form of Fourier's Law is used as shown in Equation (1):

$$Heat\ flux = q = k\frac{T_2 + T_1}{z_2 - z_1} \tag{1}$$

where T is the temperature at a measurement point, z is the level in the hearth, and k is the thermal conductivity of the material between measurement points. For the furnace sidewall calculations, the radial form of Fourier's Law is used as shown in Equation (2):

$$Heat\ flux = q = k\frac{T_2 + T_1}{\ln\frac{r_1}{r_2} \times r_{shell}} \tag{2}$$

where r represents the radius at the measurement point and r_{shell} the inside radius of the furnace steel shell. Using the above equations and variations thereof, the algorithms are programmed to calculate the real time lining wear and freeze lining thickness over a range of refractory materials with differing thermal conductivities.

3. FURNACE LINING ARRANGEMENT

Furnaces are lined with a varying composition of refractory materials depending on the alloy being produced and whether shell cooling is employed. For Furnace no.2 at Assmang Chrome, the furnace shell is cooled with water sprays creating a water film running down the shell. The furnace hearth is air-cooled from underneath. The lining design is based on the freeze-lining concept promoted and supplied by UCAR. As shown in Figure 1 most of the lining material is carbon or graphite based. Care was taken to ensure the lining was installed accurately. The drilling of holes into the lining was also carefully done to ensure that the thermocouple insertion depth is accurate to within 1mm. Although the Lining Management System is not sensitive to varying thermocouple depths, as long as each thermocouple depth is measured and recorded for input during setup, it is important to ensure the thermocouples are installed into the designated refractory layer.

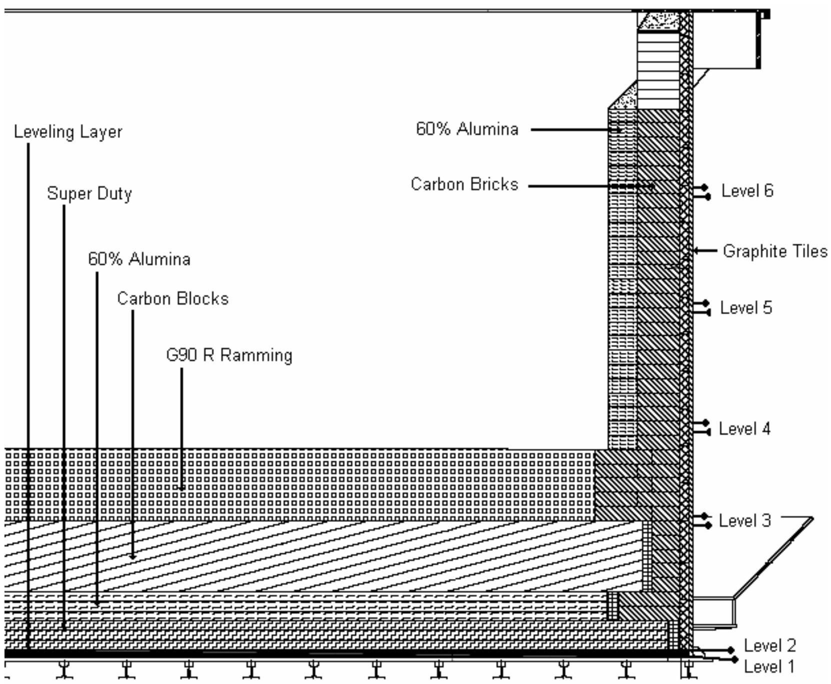

Figure 1: Furnace lining arrangement and materials used

4. HARDWARE

The System consists of numerous thermocouples placed in pairs around the furnace shell as well as in the hearth. Type K thermocouples are used with 6mm mineral insulation and pot sealed with a two-meter long teflon braided compensation tail. The thermocouples are connected to multi-core cables in junction boxes positioned around the furnace.

The thermocouple signals are connected to single channel two-way isolated transducers from where the 4.20 mA signals are connected to Allen Bradley PLC analogue input cards on a remote I/O rack. The PLC sends the signals via a PLC Ethernet card to a Standalone PC on which the Lining Management System software runs.

4.1 Thermocouple placement

The thermocouples are installed along the sidewall, subdividing the furnace into 30-degree vertical sections. The thermocouples are also installed at different levels, starting from the hearth up to the freeboard area. As a result of space restrictions, the number of tap hole thermocouples was limited.

The pairs of hearth thermocouples were installed one above the other, the spacing being such as to create an adequate layer of refractory material between the two thermocouples. This ensures a large enough temperature differential for accurate heat flux calculations. The hearth thermocouples are installed through the sidewall and not from underneath due to a space limitation and for ease of maintenance. Grooves were cut in the super duty bricks to create a protective space for the thermo wells. The sturdy thermo well design protects the thermocouple from where it enters the sidewall to its end point. For maintenance purposes, thermocouples can be removed and replaced from outside the furnace. The hearth thermocouples and thermo wells are manufactured from Inconell 600 material, having a melting point of 1412 °C. The hearth thermocouple arrangement is shown in Figure 2.

4.2 Electrical Insulation of the thermocouples

A typical problem with the thermo wells is the formation of electrical pathways to the shell. Pyromet designed an insulating bush for the thermo wells, breaking the current path between the shell and the thermo well, as well as between the thermo well and the conductive ramming or graphite material. The insulating bush and thermo well arrangement is shown in Figure 3.

The steel support runners for the thermocouple running from the furnace to the junction boxes are insulated from the furnace shell. The junction boxes where the individual thermocouples are connected to the multi-core cables are also made of a non-conductive material. The temperature transmitters situated in the junction boxes have an insulation voltage of 1.5kVAC / 50Hz.

5. INTERFACE SOFTWARE AND DATABASE

Connectivity between the thermocouples and the Lining Management System was accomplished using a software package from Rockwell™ called RSSQL™. RSLinx™ read the thermocouple temperature from the PLC and RSSQL™ inserts it into the SQL database. From here the Lining Management System software retrieves the thermocouple readings and performs the required calculations to update the real time lining wear and freeze lining formation.

Since the Assmang installation an additional OPC (open connectivity via open standards) interface was developed by Pyromet to allow for connectivity between any PLC and the Lining Management System software, provided the PLC has an OPC server software package available. The OPC client software works similar to RSLinx™, as it also reads the thermocouple temperature once a minute and writes the values to the SQL database.

The Lining Management System makes use of a Microsoft SQL 2000 database to store all readings, calculated values and thermocouple alarms. The SQL database is updated once every minute.

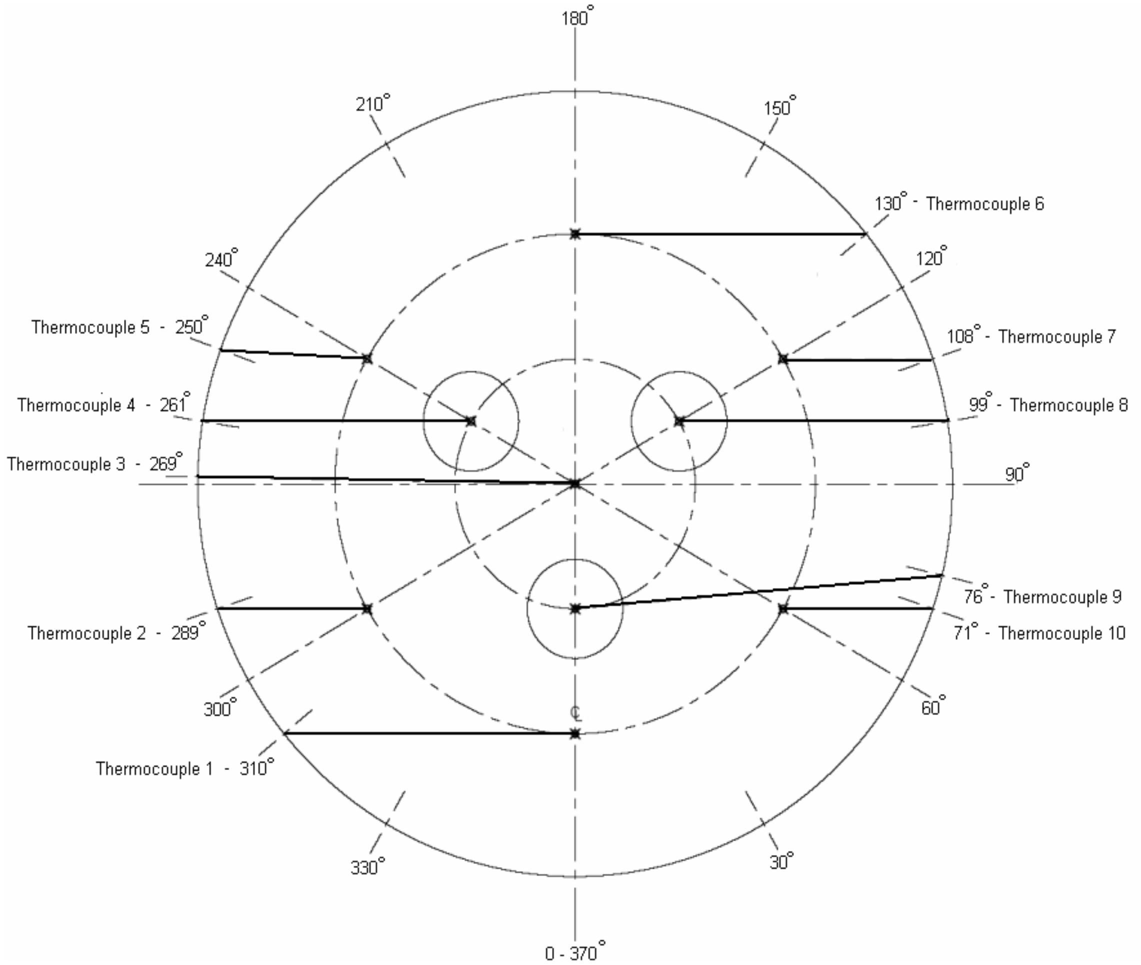

Figure 2: Hearth thermocouple layout

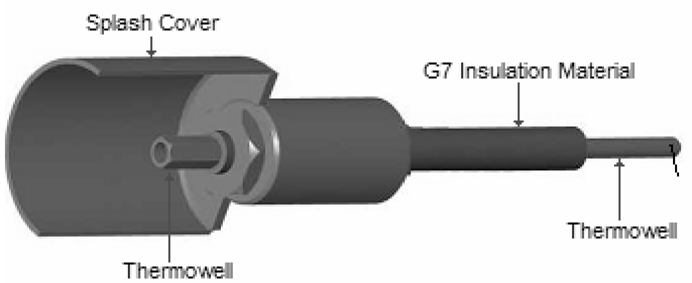

Figure 3: Insulating bush and thermo well arrangement

The Microsoft SQL database is programmed to maintain itself and performs different levels of maintenance at predefined intervals. It is important to limit the size of the database to prevent data loss and maintain the speedy retrieval of data for trending purposes. For data older than a week every fifth data reading is kept and the rest are discarded. This maintenance procedure is run twice a week. For data older than a month one reading per hour is kept and the rest are discarded. This maintenance procedure is run once every 2 weeks. For data older then three months, one reading per day is kept and the rest are discarded. This maintenance procedure as well as database backup is run once a month.

6. LINING MANAGEMENT SYSTEM SOFTWARE

The software user interface is based on the input from and requirements of the operators and engineers at Assmang. The main requirement is for the user interface to have a typical SCADA type look and feel that will be easily interpreted by the operators. Pyromet worked closely with Assmang to optimise the user interface, and to implement additional features and functionalities. Some of the additional features requested were the display of isotherms within the bath, customizable refractory wear and freeze lining displays, and specific alarm settings. Overall a great amount of time and effort was spent to make the user interface user-friendly for the plant operators.

6.1 Setup

Before running the Lining Management System, a number of settings need to be configured. Figure 4 below shows the pull down menu with the required settings that need to be configured. These are described in more detail below. The settings can be updated during operation of the system. Two different levels of authorisation are included to control access to different settings through a password input pop-up screen.

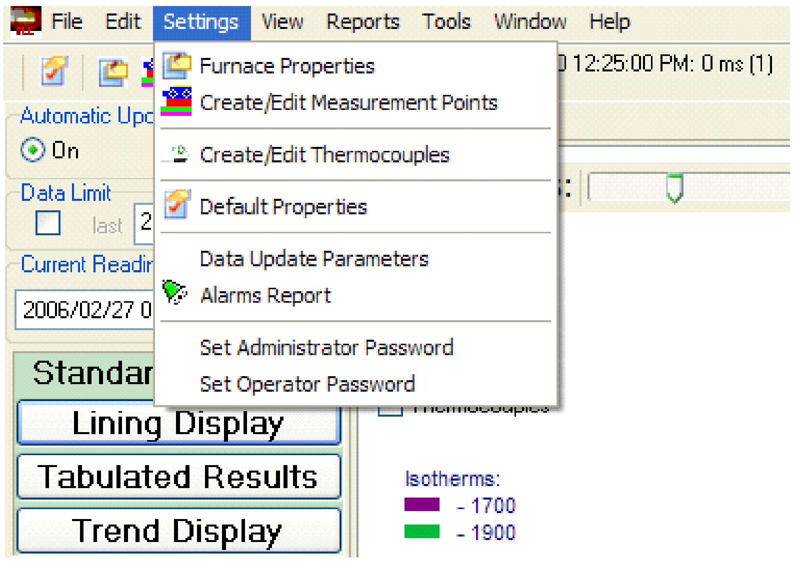

Figure 4: Lining Management Software Setup

The "Furnace Properties" input menu is used to configure the furnace dimensions, freeze temperatures, refractory wear temperatures, freeze layer conductivity, bath conductivity and the tap hole positions. The refractory wear temperatures and the freeze temperatures are required to accurately calculate the refractory wear and freeze lining thickness. The freeze layer conductivity and bath conductivity is used to calculate the isotherms within the freeze layer and the bath of the furnace. As shown in Figure 5, all values are specified relative to levels in the furnace. This allows for variation in properties depending on the process conditions in the effected area.

Under the "Creating/Edit Measurement Points" menu shown in Figure 6, thermocouples are assigned to specific measurement points on the furnace shell. Each measurement point consists of two thermocouples, one closer to the hot face and one closer to the cold face. The angular position, heat flux area and the material composition at that point are specified. Each thermocouple is associated with a thermocouple ID, a level in the furnace, and a radius relative to the furnace centre. With this configuration the measurement point is cus-

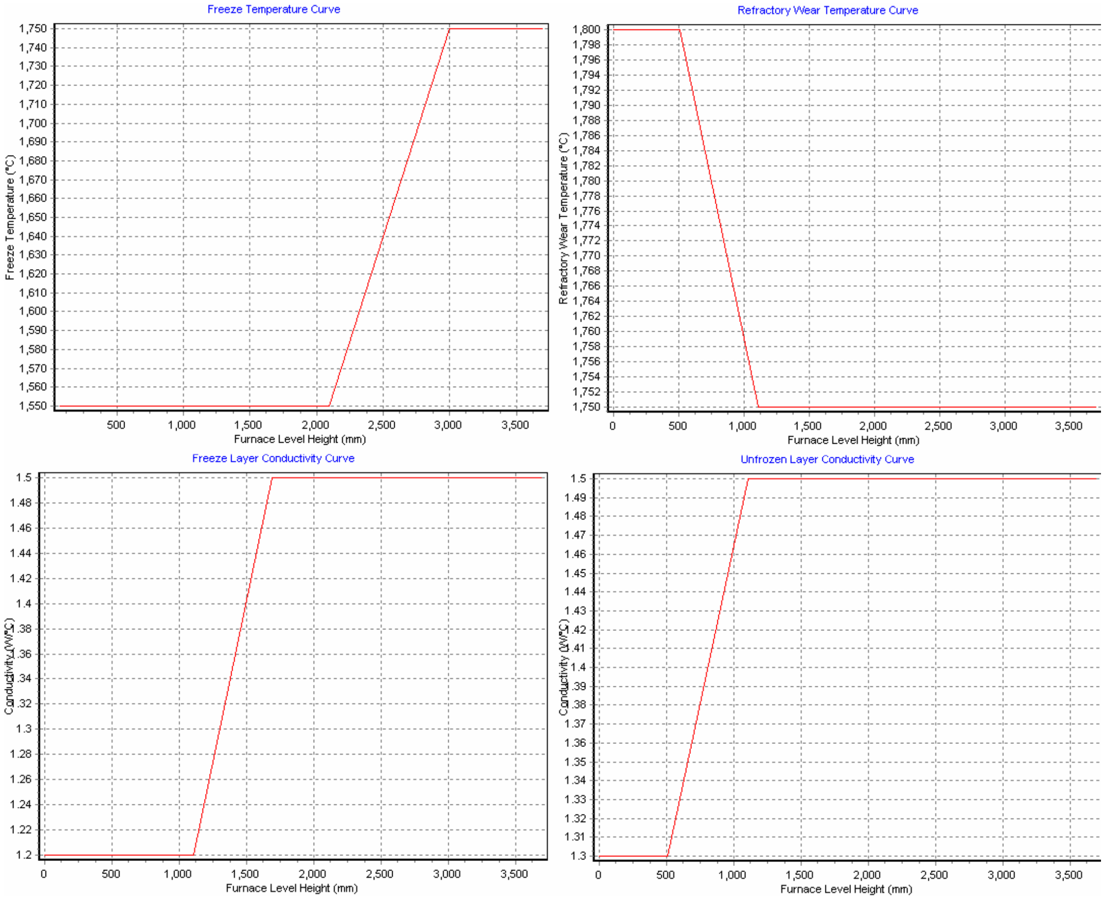

Figure 5: Configuration Input Graphs for Different Properties

tomizable and allows for additional thermocouples and measurement points to be added at a later stage. During the replacement of faulty thermocouples, the insertion depth is measured and updated to ensure accurate heat flux calculations.

In the "Create/Edit Thermocouples" menu a range of properties are assigned to each thermocouple. Maximum and minimum temperatures are defined to specify the operational range for the type of thermocouple used. Once a thermocouple reading is outside the define range, the thermocouple is assumed to be faulty and the software no longer uses the thermocouple reading in the calculations. The software will interpolate across the faulty thermocouple to keep the resulting wear profile representative. Thermocouples are also assumed to be faulty if the hot thermocouple reading is lower than that of the cold thermocouple for a specific measurement point. The operator is informed of potential faulty thermocouples and all faulty thermocouples are displayed in a list. Only the engineering personnel are authorised through a password to clear faulty thermocouples from the list after repairing or replacing them.

An operational maximum temperature is pre-calculated and set for each thermocouple. An alarm is displayed if the temperature reading exceeds this value, indicating excessively high lining temperatures. Furthermore the maximum allowable rate of temperature change is set for each thermocouple and alarmed if exceeded. The calculations continue to make use of thermocouples for which an operation alarm condition exists. All alarms are displayed in a list. Alarms are automatically removed from the list once the thermocouple reading drops back below the alarm condition.

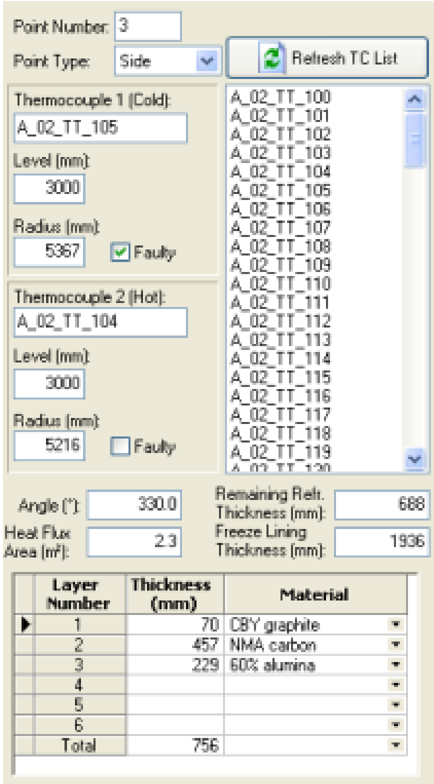

Figure 6: Measure point configuration menu

6.2 Lining display

The lining display window provides instant information to the operators and management on the furnace lining wear, freeze lining thickness and operator chosen isotherms. All of these values can be displayed relative to the original lining thickness. The operations staff can use the information to estimate remaining lining campaign life and optimise the furnace process. As an example, it is useful to evaluate the effect of process changes such as the addition of new reductants or mix recipes on operating and lining temperatures.

The lining display screen is shown in Figure 7. By selecting a radius, angle and height one is able to obtain info about the lining at any point in the furnace as shown in the information bubbles. The bubbles next to the plan view provide hearth information at the selected points. The bubbles next to the section view provide sidewall information at the selected level and section angle.

Any number of operator chosen isotherms can be displayed on the same plot. As previously discussed, these isotherms can be either inside the lining or inside the furnace bath or burden, providing useful information about conditions inside the furnace at different locations. The actual thermocouple readings can also be switched on and displayed on the same plot.

6.3 Trending

Trending allows the operator to trend either measured temperatures or any of the calculated values of a measurement point over a selected period of time. The operator is able to zoom in or out of a trend if need be. There is also the ability to print the graph or to make a software copy of the graph in bitmap format.

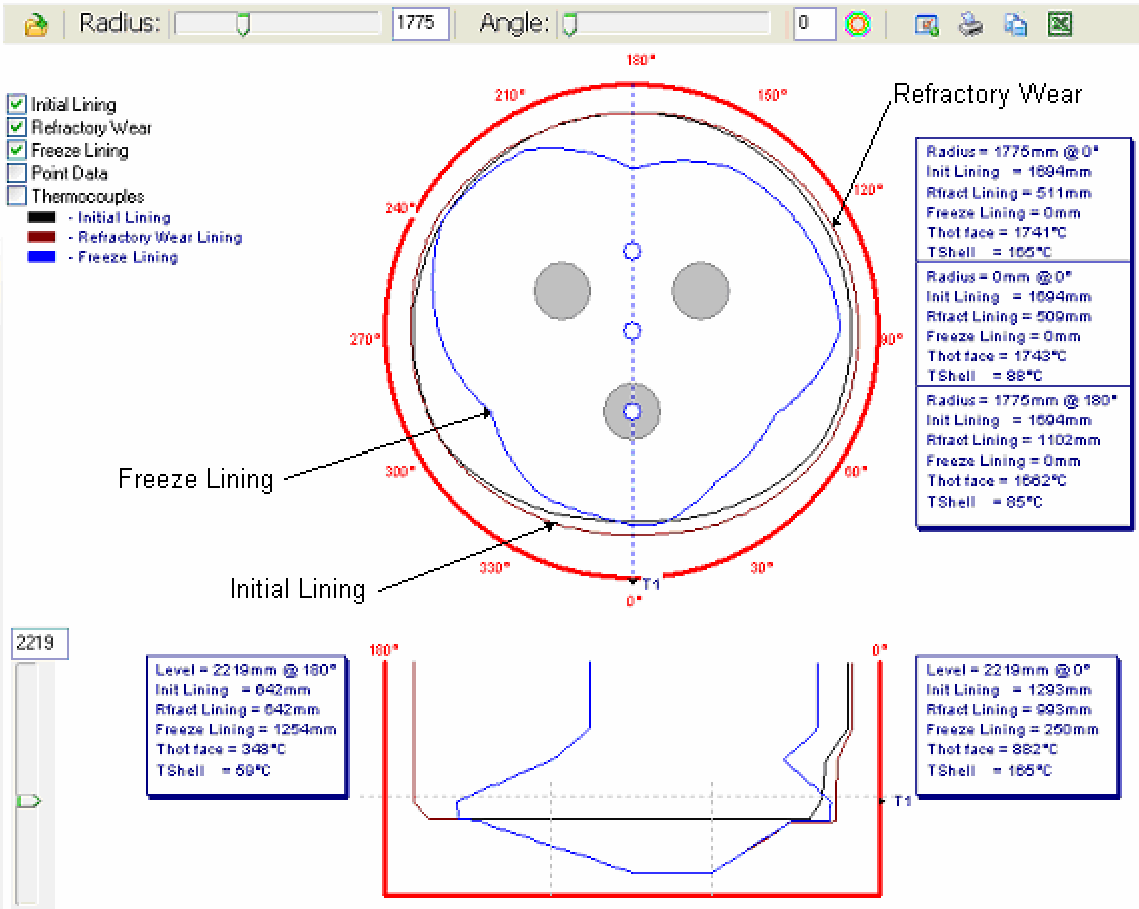

Figure 7: Lining Display Screen

6.4 Tabulated results

The tabulated results display the thermocouple measurements as well as the calculated values for each measurement point for a selected time. The tabulated data includes the hot and cold thermocouple temperatures, refractory hot face temperature, shell temperature, freeze lining thickness and remaining refractory thickness. The results can be stored either as a soft copy in excel format or a hard copy can be printed.

6.5 3-D Display

The 3-D display window shows a cut-through of the initial lining, the remaining refractory or the freeze lining. It provides an overview of the furnace crucible condition for the operator. Full manipulation of the 3-D display is possible. The operator can rotate it or zoom into a specific area as may be required. The 3-D display is shown in Figure 8.

7. OPERATIONAL RESULTS

Furnace no. 2 at Assmang's Machadodorp plant started up in September 2005 after a furnace reline. In Figure 9 the trends for the hearth thermocouples directly underneath the electrodes for the first few months of operation are shown. The three lower trends are for the three cold thermocouples while the top trends are for the three hot thermocouples. Temperatures increased sharply over the first month of operation before lev-

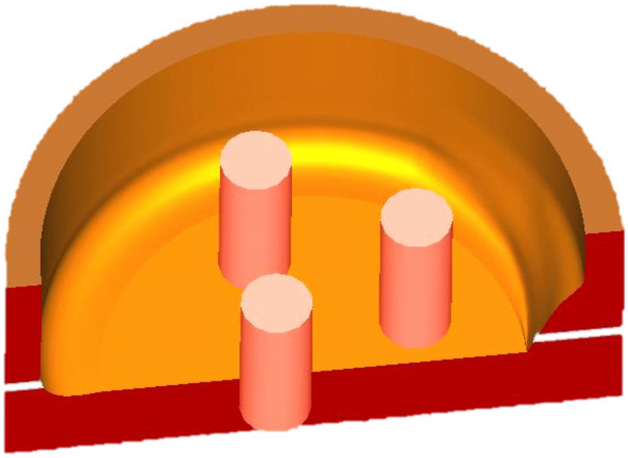

Figure 8: 3-D display of furnace crucible

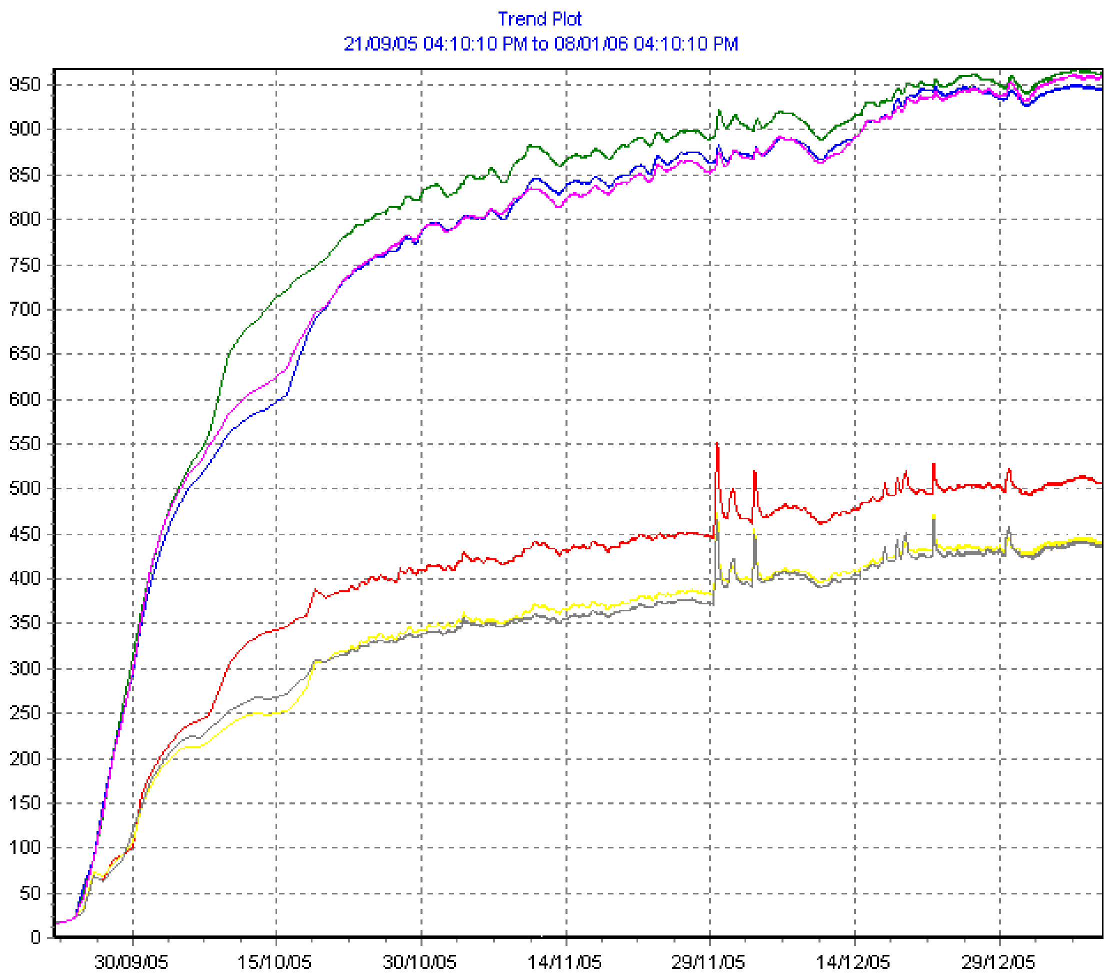

Figure 9: Furnace hearth thermocouple trends

elling off. Equilibrium was only reached in December 2005, three months after start up. The steady increase in power input to the furnace over this period also had an effect on this.

On 30 November 2005 the hearth cooling fans tripped. The effect on the cold thermocouples in the hearth is clearly visible. It had little to no effect on the hot thermocouples. On the other hand, upset conditions underneath one of the electrodes can be expected to have a more significant effect on the hot thermocouple directly underneath it, while the other hearth thermocouples should be less affected. This is a good example of how the Lining Management System can provide useful information not only on the lining condition, but also on operating conditions.

In the lining display window previously shown in Figure 7, refractory wear is visible in certain areas relative to the original lining. As can be expected, wear is more prominent in the sidewall opposite the electrodes as well as in the tap hole area. The plotted freeze lining indicates the formation of a cloverleaf typical of ferroalloy furnaces.

8. CONCLUSION

The Lining Management System developed by Pyromet and first implemented at Assmang Chrome is proving to be a useful management tool to monitor not only the furnace lining condition, but also the effect of operational changes on the process and crucible conditions. The system has been optimised over the first nine months of operation to be user friendly for both furnace operators and management alike. The lining display screen provides operators with instant information on lining and crucible conditions based on real time data. The trending facility provides management with a tool to estimate remaining lining life and understand the effect of specific operating practices on lining wear and crucible conditions.

For a furnace designer such as Pyromet, the feedback from the Lining Management System is useful in optimising future furnace designs. The effect of cooling on limiting lining wear in high heat load areas such as found in the sidewall opposite electrodes could be monitored.

For the future it is Pyromet's intention to integrate the Lining Management System with other furnace control and monitoring systems, such as the furnace electrode controller and electrode breakage detection system, to create a comprehensive Furnace Expert System that will be a powerful furnace management and information tool.

9. ACKNOWLEDGEMENT

Pyromet Technologies would like to thank Assmang Chrome, and their site personnel at the Machadodorp Works, for the opportunity to install and optimise the first Lining Management System.

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[1] Holman, J.P., "Heat Transfer", Mechanical Engineering Series, McGraw-Hill Book Co., 1989.