CHAPTER 2: OVERVIEW

2.1 INTRODUCTION

In order to relate the process and the dissertation project to each other, an overview is given in this chapter. The technical overview discusses first the off-gas system, then the water-cooled duct within the off-gas system, and then the EAF itself. The chronological order of actions performed is briefly outlined. A project overview is also given.

2.2 TECHNICAL OVERVIEW

2.2.1 Off-Gas System Overview

For a complete technical overview of EAF systems see [15]. The off-gas system under study consists of a water-cooled duct, overhead extraction canopy, three-pass air-cooled duct, six-unit baghouse filter, forced-draught fan and smoke stack. This is shown in Fig.2.1. For simplicity, elements such as the dust conveyer belt and the various emergency valves are omitted.

The baghouse of the off-gas cleaning system imposes limits on the maximum inlet temperature of the off-gas, the maximum CO content of the off-gas and the maximum differential pressure across the filters. If the temperature of the off-gas that enters the baghouse filter is too high, the baghouse may catch fire and explode. If the CO part of the gas composition that enters the baghouse filter is too high, it may also ignite and explode. If the differential pressure over the baghouse filter is too high, many of the filter bags could be ripped apart due to the high mass-flow rate in the baghouse and the resulting high stresses and pressures.

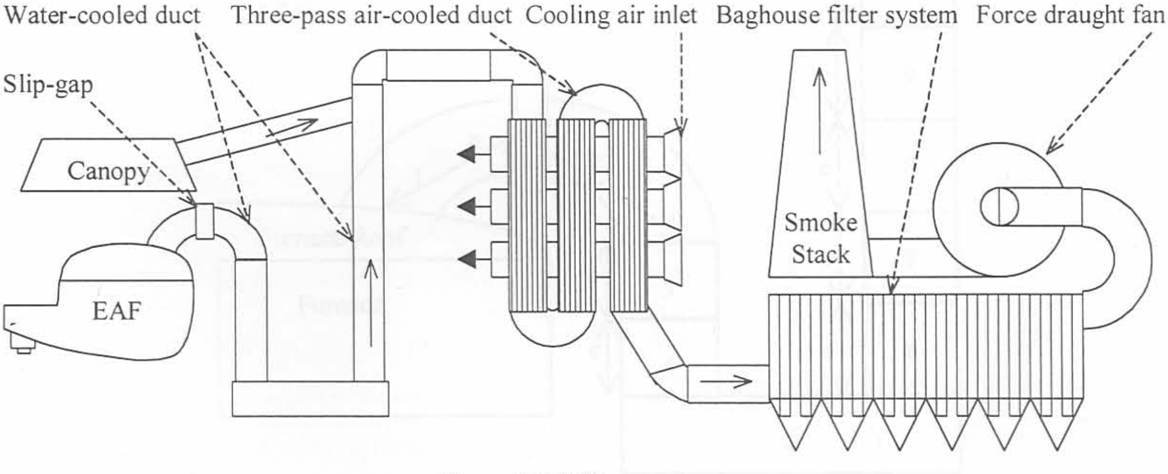

Figure 2.1 Off-gas system

A speed-controlled motor powers the force-draught fan. Due to the limitation on differential pressure over the baghouse, the operating range of the fan is limited. In general the fan has a nominal draught-force that is less than the critical limit determined by the baghouse.

Air is entrained through the slip-gap to combust CO in the EAF gas, as no combustible gases should reach the baghouse. The slip gap is situated near the EAF in the cooling duct. The slip-gap should under no circumstances be closed, because excess air is needed to combust the CO in the off-gas. Typical slip-gap widths vary from 0.1 – 0.5 m.

Valves at the top of the water-cooled duct are operated to determine the flow of gas. If the valve to the water-cooled duct is open, then the valve to the overhead canopy is closed, or *vice versa*.

2.2.2 Cooling Duct Overview

The off-gas water-cooled duct under study consists of 11 sections that are specially equipped with forced circulation water-cooling ribs on the inside. The dimensions of the duct are given in Fig.2.2, which is not drawn to scale. The cross section of the duct has an elliptic shape. For section one, which is fixed to the EAF roof, the cross sectional area is approximately 3.4 m^2, for sections two to five the cross sectional area is 4.4 m^2, and for sections six to eleven the cross sectional area is 5 m^2. An adjustable section between sections one and two can be used to regulate the slip gap. In practice this section is adjusted manually only when process requirements change.

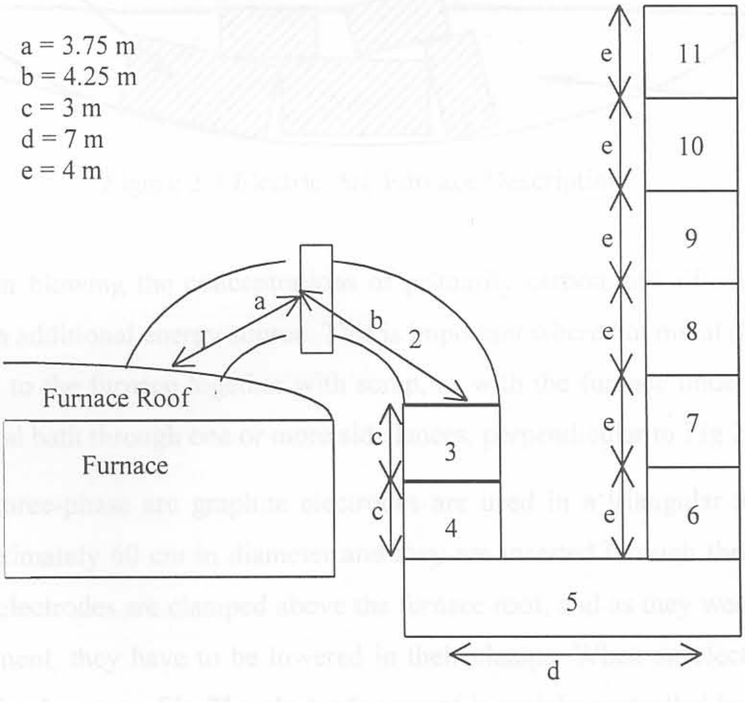

Figure 2.2 Cooling duct overview

Energy from the CO combustion reaction increases the temperature of the off-gas in the cooling duct, which requires forced circulation of cooling water. The rates of flow in the forced circulation water-cooling ribs are constant, and the water enters at 33°C. This was a nominal temperature given on the design drawings. The cooling water flow is pre-calculated for optimal cooling.

2.2.3 Electric Arc Furnace Overview

EAFs produce steel by melting scrap typically using a three-phase electrical supply. When the furnace is in operation, the furnace roof is closed. For the furnace under study the diameter is 10 m and the freeboard volume 175 m^3. Fig.2.3 gives a graphical description of the EAF with the main components and material phases shown.

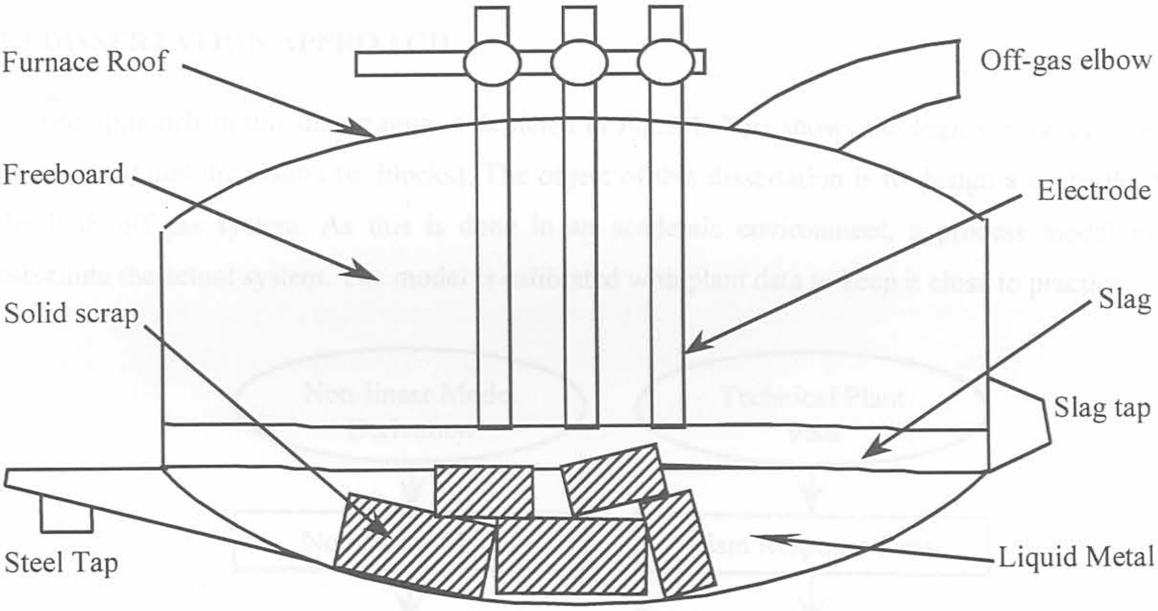

Figure 2.3 Electric Arc Furnace Description

Through oxygen blowing the concentrations of primarily carbon and silicon can be lowered, whilst providing an additional energy source. This is important where hot metal (high in carbon and silicon) is charged to the furnace together with scrap, as with the furnace under study. Oxygen is blown into the metal bath through one or more side lances, perpendicular to Fig.2.3 (into the page).

To create the three-phase arc graphite electrodes are used in a triangular arrangement. Each electrode is approximately 60 cm in diameter and they are inserted through three openings in the furnace roof. The electrodes are clamped above the furnace roof, and as they wear out in the highly corrosive environment, they have to be lowered in their clamps. When an electrode becomes too short another is joined on top of it. The electrode current is mainly controlled by means of on-load transformer tap-changers in the high-voltage winding [15,16]. The arc is also regulated/stabilised by means of electrode position (adjustment of arc length – impedance based control) [15,17].

DRI and slag additions are charged into the furnace by means of conveyer belts in the second half of the tap. Temperature control is possible by matching the DRI addition rate to the electrical power input rate [18]. "Foaming slag" and "hot heel" practices are commonly employed in EAF operations. With the foaming slag practice graphite is blown with compressed air into the slag, where it reacts with FeO to form CO that bubbles and make the slag foam, improving the arc efficiency. With the hot heel practice about 10% of the tap weight of steel is kept in the furnace after each tap. At the end of a tap, slag is removed through the slag door and the steel is tapped through the tap door. For discussion of EAF practices see McIntyre and Landry [19].

2.3 DISSERTATION APPROACH

The approach in this dissertation is depicted in Fig.2.4. This shows the logical flow of actions (in ellipses) and the results (in blocks). The object of this dissertation is to design a controller for the EAF off-gas system. As this is done in an academic environment, a process model must substitute the actual system. The model is calibrated with plant data to keep it close to practice.

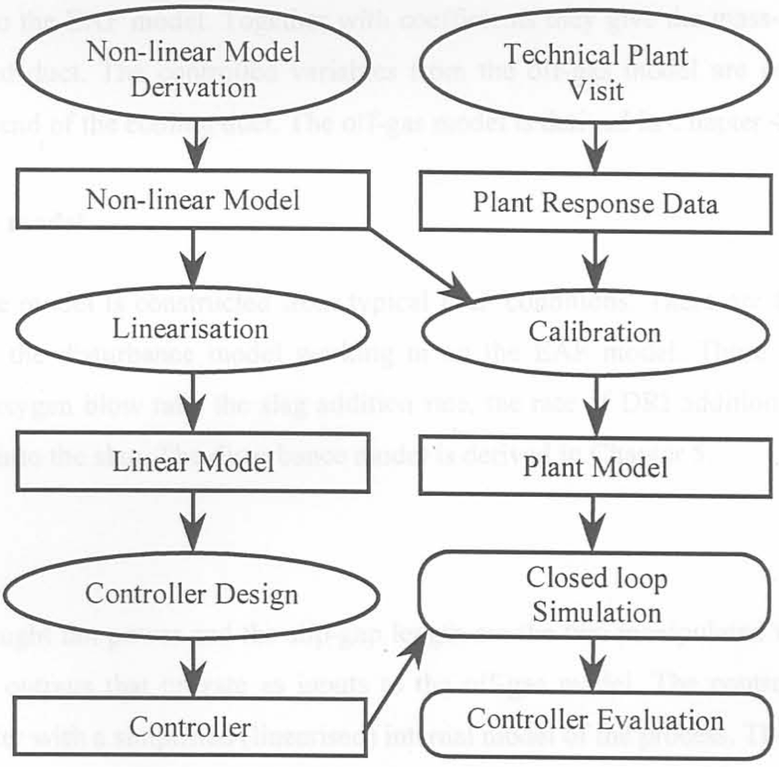

Figure 2.4. Dissertation approach

2.4 PROJECT OVERVIEW

There are four building blocks in the project. These are the disturbance model, the EAF model, the off-gas model and the controller. Fig.2.5 shows the interaction of the various parts in the project. The furnace model and the off-gas model are combined as a complete model for simulation-purposes. The simulation user specifies controller setpoints.

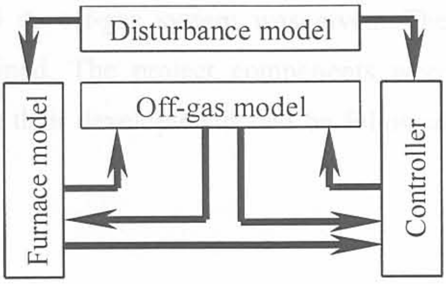

Figure 2.5 Project Overview

2.4.1 EAF model

The CO and CO_2 fractions and the temperature of the gas-phase at the slip-gap are outputs of the EAF model that operate as inputs to the off-gas model. The controlled variable from the furnace model is the pressure of the gas-phase. This is a measured variable for the controller. The EAF model is derived in Chapter 3. The EAF model and the off-gas model are combined as one model.

2.4.2 Off-gas model

There are two off-gas model outputs (combined with coefficients for physical significance) that operate as inputs to the EAF model. Together with coefficients they give the mass-flow of off-gas in the water-cooled duct. The controlled variables from the off-gas model are composition and temperature at the end of the cooling duct. The off-gas model is derived in Chapter 4.

2.4.3 Disturbance model

The disturbance model is constructed from typical EAF conditions. There are five measurable disturbances from the disturbance model working in on the EAF model. These are the electric power input, the oxygen blow rate, the slag addition rate, the rate of DRI addition and the rate of graphite injection into the slag. The disturbance model is derived in Chapter 5.

2.4.4 Controller

The forced-draught fan power and the slip-gap length are the two manipulated variables. These are the controller outputs that operate as inputs to the off-gas model. The controller is a model predictive controller with a simplified (linearised) internal model of the process. The internal model is derived from the combined plant model as discussed in Chapter 6 and analysed in Chapter 7. The initial controller design is in Chapter 8. The control implementation is discussed in Chapter 9.

2.5 CONCLUSION

In this chapter the technical overview of the EAF and its off-gas system was given. The dissertation approach and the project overview were outlined. The project components were discussed and the respective places in the dissertation where their developments can be followed were given.