CHAPTER 10: CONCLUSION AND RECOMENDATIONS

10.1 SUMMARY OF APPROACH

The subject treated in this dissertation was motivated from industrial practice, and a solution was obtained that could be applied in the actual plant control system. Since no plant model was available, an extensive modelling effort was conducted. The model derived in this dissertation was intended for the testing of control strategies using off-gas variables in the control of an EAF. Derivation of a multivariable non-linear state-space model for the process was treated. The assumptions that were made and the state space representation provided a comprehensive framework for the development of an EAF process model. First principles of thermodynamics were then used to derive the model, ensuring behaviour consistent with physical observations. Typical operating conditions for a furnace were discussed, and a simulation was conducted with these operating conditions. In order to apply the model to represent a specific industrial furnace, the adjustable parameters in the model were selected such that the model responses concur with those of the actual furnace. After verification this plant model was then regarded as the process for which a controller had to be designed. A linear model approximated the plant model to give a simplified mathematical abstraction of the process. It was accepted as a reasonable approximation of the process, and an analysis of the linear system showed that it is stable. The analysis also showed that the linear system is output controllable, although the internal state vector is not completely observable. Qualitative control objectives were translated to quantitative control specifications.

Controller design for the linear system was performed in the Matlab environment. Model Predictive Control was the preferred control design method, due to the use of an internal model and the use of optimisation. Experiments with the controller parameters were done to obtain the best nominal controller. These include the cost function multipliers for the controlled and manipulated variables, as well as the control and prediction horizons. The effect of various inputs and disturbances was determined. The emphasis was divided between improving EAF efficiency and ensuring environmental protection and the nominal controller was obtained. Integral action was required to eliminate offsets, and it was added to the unforced response. The controller was then applied to the plant model, and tested on the process it was intended for. The controller was evaluated against the option of manual control, and achieved much improved performance.

10.2 CONTRIBUTION OF THIS WORK

The main contribution of this dissertation is to demonstrate the feasibility of using the off-gas variables for EAF process control. Since many unsteady-state models are proprietary, they are not published in the literature. There are a few exceptions [7,13], which give partial model derivations for EAF processes. The model derived in this dissertation, and the publication of it, is therefore seen as an important contribution to the literature. With the GCP [14] as guideline, MPC was applied to the process [11] and evaluated, and this is also seen as a relevant contribution. One publication in an international journal [7] on the subject of the metallurgical modelling of the EAF process, and two conference articles (IFAC MMM) [8,11] have been published on the work done in this dissertation.

In order to assert the value of this dissertation to the engineering community, it is necessary to review its purpose. In the particular industrial process treated in this dissertation, automatic control systems have not yet been used to improve the process efficiency by regulating the off-gas process. This dissertation shows that it will be possible to do just that, and it also elaborates on the method to be used. When the knowledge gained through this dissertation is applied on an industrial EAF, it will result in an improved regulation of the EAF relative pressure, which will in turn result in less energy waste and higher process efficiency. In the competing environment of the global economy the application of such a new automatic control system to an existing production facility, should prove beneficial, even if only small efficiency improvements are reached.

Another result of this dissertation is the example of the method to practically apply MPC to an industrial process. There are several practical points that have to be considered when MPC is applied, such as the interface between the absolute variables of the "outside world" and the deviation variables of the internal model of the controller. Problems such as these and others have been treated in this dissertation, and therefore present an example of MPC application to an industrial process.

10.3 RECOMMENDATIONS

The recommendations given here are for future work that can be undertaken in undergraduate projects or in postgraduate dissertations, depending on the level of complexity.

The following recommendations for further work are concerned with modelling:

1. The gas phase system, including the furnace freeboard and the water-cooled duct, should be modelled by Computational Fluid Dynamic (CFD) modelling, supported by combustion modelling. This problem will probably have to be made two-dimensional, if not three-dimensional, to obtain sufficient accuracy. An attempt to achieve this by means of a one-dimensional CFD model was done for this dissertation, but failed to achieve the necessary accuracy. The derivation is shown in [59], and can be taken as a guideline for initial work in such a project. It must be emphasised here that a dynamic model is required, in contrast with steady state CFD simulations, examples of which are also shown in [59]. Such a dynamic

model will significantly enhance the accuracy of the off-gas model, and it will improve further understanding of the process.

2. The exact relationship between electrode position, transformer tap positions and power transfer to the liquid metal pool should be modelled and incorporated into the model. The effect of the slag-depth will also have to considered. The motivation for this additional modelling is that it will enable the control engineer to include the transformer tap position and electrode position as manipulated variables in the control design.
3. The phosphorus content in the liquid metal pool should be taken into account. This implies that the chemistry (e.g. basicity of the slag, FeO and MgO content of the slag, amount of CaO dissolved in the liquid phase) and temperature of the slag should also be considered.
4. The cooling water measurements of the furnace and duct walls must be taken into account.

The following recommendations for further work are concerned with control applications:

1. With the electrical model available, and added to the existing model, the control engineer can use the electrode position, the transformer tap position and also the DRI feed rate as manipulated variables in the controller design to control the liquid metal pool temperature and the tap-to-tap time
2. With the slag-basicity and phosphorus relationship modelled and added to the existing model, the control engineer can use the slag-addition inputs as manipulated variables to control the slag-basicity and the dephosphorisation rate.
3. The entire process (with all models included) should be implemented on an industrial furnace. All the available MVs should be used to control the entire operation. This should be integrated with existing control systems to yield a complete Computer Integrated Manufacturing (CIM) system [60].