CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS.

8.1. SUMMARY OF DISSERTATION CONTENTS.

In Chapter 1 a motivation of the project was presented and some background given to place the study's contribution to the literature in context.

Chapter 2 contained a technical overview of the EAF process, the simulation model used and control objectives typically specified in industry. The EAF model was expanded by modelling the slag foam depth.

In Chapter 3 the EAF was analysed from an economic perspective. The cost contribution of the feed materials was determined as well as the economic implication of not reaching the control objectives described in Chapter 2.

Chapter 4 provided the theoretical background on Model Predictive Control (MPC) and the applicability of MPC to the control problem was discussed.

Chapter 5 showed the design of a linear MPC controller based on economic objectives. The linearisation of the non-linear EAF model was discussed, and some implementation issues in ensuring representative simulations mentioned. The calculation of appropriate weights based on economic objectives was discussed, and the choices for other tuning parameters motivated. Finally a simulation was done to compare the EAF under manual and MPC control and to determine if all functional control objectives are met.

In Chapter 6 a theoretical background on the evaluation of systems was provided. The statistical and capital budgeting tools required were discussed and experimental techniques described, that would ensure the generation of statistically significant data in noisy environments. An evaluation framework was presented that would ensure that reliable data would be generated and that valid experimental results can be obtained.

Chapter 7 contained the final simulation study based on the experimental techniques and evaluation framework presented in Chapter 6. The MPC controller designed in Chapter 5 was compared to the EAF under manual control in the presence of typical disturbances, and subject to operational conditions typically found in industry. The data was analysed and hypothesis tested to determine if a statistically significant result could be obtained. The potential economic benefits of implementing an MPC controller was quantified and the major sources of potential savings identified.

The contribution can thus be summarized as follows:

1. The expansion of the available EAF model by modelling the slag foam depth.

2. The presentation of a structure to translate functional control objectives into economic objectives.

3. The design and simulation of an MPC controller, based on design criteria that would minimise the cost of EAF operation.

4. The suggestion of an evaluation framework to ensure that useful data are generated and that the data is analysed appropriately.

5. Quantifying the potential economic benefits of implementing an MPC controller on an EAF, based on a detailed simulation study.

8.2. CONCLUSIONS.

The slag foam depth is an important variable in minimizing heat losses in an EAF. The expansion of the existing EAF model to include the slag foam depth provides a useful framework to optimise the complete EAF steelmaking process. Although the slag foam depth model was not utilized to the maximum extent in the simulation study (definition as a state variable to be used in other state equations), further integration into the existing model can improve model accuracy significantly.

An analysis of the EAF steelmaking process from an economic perspective provides valuable insight into the relative importance of control objectives that are typically specified in industry. By adjusting the priorities of the control objectives according to their economic

impact on the EAF steelmaking process, the process can be operated in an economically optimal way. MPC provides the infrastructure to specify the priorities of a number of control objectives based on economic considerations. Implementation of an MPC controller based on economic objectives proves to be effective in reducing the cost of EAF steelmaking without exceeding any of the physical limits.

Large potential economic benefits exist in the implementation of an advanced control strategy e.g. MPC on EAFs. Minor benefits (0.81 % reduction in operating cost) are predicted due to more efficient utilization of feed materials and energy inputs. As static furnace models are used extensively in industry in predicting optimal feed additions, limited benefits in improved feed material utilization were expected. The major portion of the predicted benefits (7.17 % reduction in operating cost) is due to the elimination of unscheduled delays. Unscheduled delays caused by not meeting steel temperature and composition specifications at tapping, or exceeding the maximum off-gas temperature can be eliminated completely using MPC. All these economic benefits were achieved without compromising the health of workers or by increasing emissions excessively. The simulations were also based on configurations and instrumentation typically available in industry. Expenditure in expanding available infrastructure and implementing the suggested control strategy should thus be limited.

The assumption that operators are not capable of responding to disturbances may favour the MPC controller to a certain extent, possibly biasing the results. Some of the assumptions required in deriving the economic cost model might also be invalidated under certain operating conditions, especially the assumptions concerned with influences that can not be quantified, e.g. the influence on the health of a number of workers. The major portion of the predicted economic benefits is however based on the elimination of unscheduled delays, which is modelled with sufficient accuracy. Due to modelling inaccuracies the predicted benefits might thus vary slightly from the actual benefits that can be achieved on a specific plant. The potential benefit (in excess of 8 %) is however of sufficient magnitude to ensure that the influences due to modelling inaccuracies are negligible.

8.3. RECOMMENDATIONS.

The following recommendations are made regarding future work on the EAF model and its application:

1. The model should be expanded to include the phosphorus, sulphur and manganese content of the melt and also the slag basicity. These variables were mentioned in the control objectives defined in Chapter 2, but were omitted from the final control objectives due to the lack of accurate models. Inclusion of these variables in the model would allow flux additions to the slag to be optimised, by adding flux additions to the current list of manipulated variables.

2. The relationship between electrode position, transformer tap position and power transfer to the melt should be incorporated into the model. The slag foam depth can also be incorporated into this model, to model power transfer more accurately. This would allow the electrical input to the EAF to be used as a manipulated variable and not as a disturbance input as is currently used.

3. Cooling water measurements of the furnace and duct walls need to be taken into account, as these are continuous measurements, compared to the discrete measurements used for the metal temperature. Accurate modelling of the relation between the cooling water temperature and the bath temperature can increase the efficiency of temperature feedback significantly.

4. The control strategy with all the models should be implemented on an industrial EAF. All the traditionally manually controlled variables should be substituted with automatic control to evaluate the efficiency of the MPC controller. The efficiency of the MPC controller based on economic objectives can be evaluated in this way, and also the accuracy of the simulator.