# CHAPTER V

# CONCLUSIONS & RECOMMENDATIONS

## 5.1 Conclusions

This study was performed primarily to determine how the operational parameters of the grate clinker cooling system and the recovery of heat from the hot exhaust air, affect its first and second law efficiencies. Cost benefit and emission reduction shall result from the energy and exergy efficient clinker cooler.

The conclusions that can be drawn based on the analyses performed on the energy and exergy efficiencies of the grate clinker cooling system are:

i) The energy efficiency of the base case clinker cooler is 81.2%, while the energy recovery efficiency is 51.2%. On the other hand, the exergy efficiency of the base case clinker cooler is 53.7%, while the exergy recovery efficiency is 43.1%. Energy and exergy efficiencies represent the overall performance of the grate clinker cooling system, while the energy and exergy recovery efficiencies only take into account the heat recovered and used at other phases of the clinker production.

ii) For every 5% increment in mass flow rate of cooling air, the energy efficiency and the energy recovery efficiency of the clinker cooling system increase an average of 1.1% and 1.9% respectively. The average increment of exergy and exergy recovery efficiencies on the other hand, are 0.9% and 1.5% respectively.

As the mass flow rate of cooling air is increased, more energy and exergy are able to be absorbed by the increased air flow and returned to the rotary burner and the pre-calciner as secondary and tertiary air.

iii) For every 5% increment in temperature of cooling air, the energy efficiency and the energy recovery efficiency of the clinker cooling system increase an average of 2.0% and 0.4% respectively. The average increment of exergy and exergy recovery efficiencies on the other hand, are 3.6% and 2.2% respectively. The fall of cooling air temperature causes internal energy and exergy losses, despite the slight increase in the amount of energy that the lower temperature cooling air is able to recover.

iv) For every 5% decrement in mass flow rate of clinker, the energy efficiency and the energy recovery efficiency of the clinker cooling system increase an average of 2.7% and 2.5% respectively. The average increment of exergy and exergy recovery efficiencies on the other hand, are 2.4% and 2.2% respectively. More volume of cooling air per weight clinker, as well as an increase in residence time for the air to cool down the hot clinker leads to improved first and second law efficiencies.

v) For every 9.1% increment in grate speed, the energy efficiency and the energy recovery efficiency of the clinker cooling system increase an average of 3.5% and 1.4% respectively up to 18.2% increment in grate speed. The average increment of exergy and exergy recovery efficiencies on the other hand, are 3.1% and 1.7% respectively. The grate speed affects the residence time of clinker for cooling and the bed height, which will affect the first and the second law efficiencies of the system.

vi) With the assistance of heat recovery from the exhaust air, typical grate clinker cooling system experiences 21.5% in energy recovery efficiency and 9.4% in exergy recovery efficiency. Instead of rejecting useful heat to the surrounding, the system gains improvement in the first and the second law efficiencies when this heat is returned to other phases of clinker production.

vii) From the cost benefit analyses performed, decreasing the mass flow rate of clinker is the most benefitial way to improve the system's efficiencies, in terms of the payback period taken, the present value of investment and the cost of energy conserved. The results from the emission reduction analyses also suggest that reducing the mass flow rate of clinker contributes the most towards the reduction of major air pollutants such as $NO_x$, CO and PM, as well as green house gas $CO_2$.

## 5.2 Recommendations

Listed below are some of the recommendations that could be taken into consideration for further research:

i) The results of the analyses were based upon estimations of the temperature profiles of the air and the hot clinker developed from theoretical model of a grate clinker cooling system. More accurate analyses can be performed with the presence of a complete range of modelled data for the grate clinker cooler, i.e. temperature and pressure profiles with variation in its operational parameters, as well as the entropy generation analyses to further support the outputs.

ii) The cost benefit analyses performed take into account the initial investments and the incremental operations and maintenance costs incurred. More accurate analyses require actual, detailed and consistent costing taken from cement plants around the world with specific process types and plant outputs. An average of every type of cost incurred from these plants would paint a better picture of the current study.

iii) The emission reduction analyses conclude the theoretical emission reduction as a consequence of thermal energy savings. In actual, changes in the chemical composition and the energy content of the clinker also contribute to changes in emission of major air pollutants such as the $NO_x$, $SO_x$, CO and PM, as well as the greenhouse gas $CO_2$. Optimization of the operational parameters of the grate clinker cooler also affects the thermal energy requirements of the clinker and its chemical composition in other phases of cement production, and hence the emissions of these pollutants. Further studies on the effects of thermal energy requirement in these other phases can help justify the investments to be made for such energy efficiency measures.