# IMPROVING HEATING PLANT EMISSIONS USING FLUE GAS CARBON MONOXIDE MONITORING

A thesis presented in partial fulfilment of the requirements for the degree of Masters of Engineering in Automation and Control at Massey University

**Jokha Hamood Al Shukairi**

**2011**

# SUMMARY

RCR Energy Systems builds industrial heating plants and their control systems. In these the excess air (above the stoichiometric ratio) for combustion is a process variable and its setpoint is determined using a look-up table. RCR aims to improve the efficiency of wood-fired, thermal-oil heating plants by using a combination of carbon monoxide monitoring and oxygen trim control to automatically adjust the excess air setpoint.

Heating plants require the correct amount of oxygen for combustion. Too little excess air does not allow complete combustion, producing a loss in efficiency and wasted fuel. Too much excess air reduces the flame temperature with a consequent drop in heat transfer rate and loss of efficiency.

The aim of the project was to explore the advantages of carbon monoxide monitoring and oxygen trim control, as well as its application, design and implementation in trimming excess oxygen setpoint, to a lower, but still safe operating level.

Various carbon monoxide monitoring and oxygen trim control schemes were researched with the most suitable being implemented on an industrial system using a combined carbon monoxide and oxygen measurement analysers. This scheme was then tested on the heating plants at Hyne & Son in Tumbarumba, Australia. The tests proved that the excess air setpoint could be successfully reduced by 2%, leading to an approximate 3 – 5% improvement in efficiency.

## ACKNOWLEDGEMENTS

*I am grateful to my parents for giving me the opportunity to study a Masters degree in New Zealand. I would also like to thank my supervisor Dr Huub Bakker for his help and advice throughout my academic career. Thanks also to my mentor Allen Keogh, automation and electrical manager at RCR Energy Systems, for his support while working on the project. My gratitude extends to Nick Martin and Kelly Williams, engineers at RCR Energy Systems, for putting up with me and providing me with a lot of help and knowledge which assisted with the project.*

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# NOMENCLATURE

| SYMBOL | DESCRIPTION | UNIT |
|---|---|---|
| $a_1$ | Carbon content of grate ash, %wgt | % |
| $a_2$ | Carbon content of fly ash , %wgt | % |
| CO | Carbon monoxide | ppm |
| $COSP_{HP1}$ | Heating plant 1 carbon monoxide setpoint | ppm |
| $COSP_{HP2}$ | Heating plant 2 carbon monoxide setpoint | ppm |
| $COT_{PH1}$ | Heating plant 1 carbon monoxide transmitter | ppm |
| $COT_{PH2}$ | Heating plant 2 carbon monoxide transmitter | ppm |
| $Cp_{AmbHP}$ | Heating plant ambient temperature specific heat capacity | J/kg. °C |
| $Cp_{FlueHP1}$ | Heating plant 1 flue gas temperature specific heat capacity | J/kg. °C |
| $Cp_{FlueHP2}$ | Heating plant 2 flue gas temperature specific heat capacity | J/kg. °C |
| $Cp_{FlueNewHP}$ | Heating plant flue gas temperature specific heat capacity with increased 2% in excess air | J/kg. °C |
| $Cp_{FurnHP1}$ | Heating plant 1 furnace air temperature specific heat capacity | J/kg. °C |
| $Cp_{FurnHP2}$ | Heating plant 2 furnace air temperature specific heat capacity | J/kg. °C |
| $Cp_{FurnNewHP}$ | Heating plant furnace air temperature specific heat capacity with increased 2% excess air | J/kg. °C |
| $Cp_{HEHP}$ | Heating plant heat exchanger outlet air temperature specific heat capacity | J/kg. °C |
| $Cp_{HENewHP}$ | Heating plant heat exchanger outlet air temperature specific heat capacity with 2% increase in excess air | J/kg. °C |
| $Cp_{OilHP1(33\%Texa+67\%Prf)}$ | Heating plant 1 heat transfer oil specific heat capacity (33% Texatherm 32 + Perfecto HT12) | J/kg. °C |
| $Cp_{OilHP2(33\%Texa+67\%Prf)}$ | Heating plant 2 heat transfer oil specific heat capacity (33% Texatherm 32 + Perfecto HT12) | J/kg. °C |
| $Cp_{OilInHP1Prf}$ | Heating plant 1 Perfecto HT12 inlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilInHP1Texa}$ | Heating plant 1 Texatherm 32 inlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilInHP2Prf}$ | Heating plant 2 Perfecto HT12 inlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilInHP2Texa}$ | Heating plant 2 Texatherm 32 inlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilOutHP1Prf}$ | Heating plant 1 Perfecto HT12 outlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilOutHP1Texa}$ | Heating plant 1 Texatherm 32 outlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilOutHP2Prf}$ | Heating plant 2 Perfecto HT12 outlet oil specific heat capacity | J/kg. °C |
| $Cp_{OilOutHP2Texa}$ | Heating plant 2 Texatherm 32 outlet oil specific heat capacity | J/kg. °C |
| $E_{gr}$ | Thermal efficiency | % |
| $E_{HP1}$ | Heating plant 1 efficiency improvement | % |
| $E_{HP2}$ | Heating plant 2 efficiency improvement | % |
| F | The flowrate of the fluid | Kg/s |
| $F_{AirHP1}$ | Heating plant 1air flow rate | kg/s |
| $F_{AirHP1+2\%}$ | Heating plant 1 air flow rate with 2% increase in excess air | kg/s |

| | | |
|---|---|---|
| $F_{AirHP2}$ | Heating plant 2air flow rate | kg/s |
| $F_{AirHP2+2\%}$ | Heating plant 2 air flow rate with 2% increase in excess air | kg/s |
| $F_{OilHP1}$ | Heating plant 1 oil flow rate | kg/s |
| $F_{OilHP1(33\%Texa+67\%Prf)}$ | Heating plant 1 oil flow rate (33% Texatherm 32 + Perfecto HT12) | kg/s |
| $F_{OilHP2}$ | Heating plant 2 oil flow rate | kg/s |
| $F_{OilHP2(33\%Texa+67\%Prf)}$ | Heating plant 2 oil flow rate (33% Texatherm 32 + Perfecto HT12) | kg/s |
| $F_{OilInHP1Prf}$ | Heating plant 1 Perfecto HT12 inlet oil flow rate | kg/s |
| $F_{OilInHP1Texa}$ | Heating plant 1 Texatherm 32 inlet oil flow rate | kg/s |
| $F_{OilInHP2Prf}$ | Heating plant 2 Perfecto HT12 inlet oil flow rate | kg/s |
| $F_{OilInHP2Texa}$ | Heating plant 2 Texatherm 32 inlet oil flow rate | kg/s |
| $F_{OilOutHP1Prf}$ | Heating plant 1 Perfecto HT12 outlet oil flow rate | kg/s |
| $F_{OilOutHP1Texa}$ | Heating plant 1 Texatherm 32 outlet oil flow rate | kg/s |
| $F_{OilOutHP2Prf}$ | Heating plant 2 Perfecto HT12 outlet oil flow rate | kg/s |
| $F_{OilOutHP2Texa}$ | Heating plant 2 Texatherm 32 outlet oil flow rate | kg/s |
| $FR_{HP1}$ | Heating plant 1 firing rate | % |
| $FR_{HP2}$ | Heating plant 2 firing rate | % |
| H | Hydrogen content of fuel as fired, %wgt | % |
| $K_1$ | Coal constant. typical value of $k_1$ for coal is 63 in accordance with British standard 845-1:1987 | - |
| $K_2$ | Weight basis percentage of the fuel | - |
| $K_{gr}$ | Constant Siegert (based on calorific value) | - |
| $L_{1gr}$ | Losses due to sensible heat in dry flue gases | % |
| $L_{2gr}$ | Losses due to enthalpy in water vapour in the flue gases | % |
| $L_{3gr}$ | Losses due to unburned gases in the flue gases | % |
| $L_{4gr}$ | Losses due to combustible matter in ash and riddling | % |
| $L_{5gr}$ | Losses due to combustible matter in grit and dust | % |
| $L_{6gr}$ | Radiation, convection and conduction losses | % |
| $L_{Tgr}$ | Total losses | % |
| $M_f$ | Mass of solid fuel fired | kg |
| $mH_2O$ | Moisture content of fuel as fired, %wgt | % |
| $N_2$ | Nitrogen content in the flue gas | % |
| $O_2$ | Oxygen content in the flue gas | % |
| $O_2SP_{HP1}$ | Heating plant 1 oxygen setpoint | % |
| $O_2SP_{HP2}$ | Heating plant 2 oxygen setpoint | % |
| $O_2T_{HP1}$ | Heating plant 1 oxygen transmitter | % |
| $O_2T_{HP2}$ | Heating plant 2 oxygen transmitter | % |
| $\rho_{OilHP1(33\%Texa+67\%Prf)}$ | Heating plant 1 oil density (33% Texatherm 32 + Perfecto HT12) | $kg/m^3$ |
| $\rho_{OilHP2(33\%Texa+67\%Prf)}$ | Heating plant 2 oil density (33% Texatherm 32 + Perfecto HT12) | $kg/m^3$ |
| $\rho_{OilInHP1Prf}$ | Heating plant 1 Perfecto HT12 inlet oil density | $kg/m^3$ |
| $\rho_{OilInHP1Texa}$ | Heating plant 1 Texatherm 32 inlet oil density | $kg/m^3$ |

| | | |
|---|---|---|
| $p_{OilInHP2Prf}$ | Heating plant 2 Perfecto HT12 inlet oil density | $kg/m^3$ |
| $p_{OilInHP2Texa}$ | Heating plant 2 Texatherm 32 inlet oil density | $kg/m^3$ |
| $p_{OilOutHP1Prf}$ | Heating plant 1 Perfecto HT12 outlet oil density | $kg/m^3$ |
| $p_{OilOutHP1Texa}$ | Heating plant 1 Texatherm 32 outlet oil density | $kg/m^3$ |
| $p_{OilOutHP2Prf}$ | Heating plant 2 Perfecto HT12 outlet oil density | $kg/m^3$ |
| $p_{OilOutHP2Texa}$ | Heating plant 2 Texatherm 32 outlet oil density | $kg/m^3$ |
| $Q_{AirinHP1}$ | Heating plant 1 air inlet power | MW |
| $Q_{AirinHP2}$ | Heating plant 2 air inlet power | MW |
| $Q_{AirinNewHP1}$ | Heating plant 1 air inlet power with 2% increase in excess air | MW |
| $Q_{AirinNewHP2}$ | Heating plant 2 air inlet power with 2% increase in excess air | MW |
| $Q_{CombHP1}$ | Heating plant 1 power generated in combustion zone | MW |
| $Q_{CombHP2}$ | Heating plant 2 power generated in combustion zone | MW |
| $Q_{CombNewHP1}$ | Heating plant 1 power generated in combustion zone with 2% increase in excess air | MW |
| $Q_{CombNewHP2}$ | Heating plant 2 power generated in combustion zone with 2% increase in excess air | MW |
| $Q_{gr}$ | Gross calorific value of fuel | kJ/kg |
| $Q_{HP1}$ | Heating plant 1 output power | MW |
| $Q_{HP2}$ | Heating plant 2 output power | MW |
| $Q_{NewHP1}$ | Heating plant 1 output power with 2% increase in excess air | MW |
| $Q_{NewHP2}$ | Heating plant 2 output power with 2% increase in excess air | MW |
| $Q_{SteamHP1}$ | Heating plant 1 steam power | MW |
| $Q_{SteamHP2}$ | Heating plant 2 steam power | MW |
| $Q_{SteamNewHP1}$ | Heating plant 1 steam power with 2% increase in excess air | MW |
| $Q_{SteamNewHP2}$ | Heating plant 2 steam power with 2% increase in excess air | MW |
| $t_3$ | Heating plant exit temperature | °C |
| $t_a$ | Ambient temperature | °C |
| $T_{AmbHP1}$ | Heating plant 1 ambient temperature | °C |
| $T_{AmbHP2}$ | Heating plant 2 ambient temperature | °C |
| $T_{FlueHP1}$ | Heating plant 1 flue gas temperature | °C |
| $T_{FlueHP2}$ | Heating plant 2 flue gas temperature | °C |
| $T_{FlueNewHP1}$ | Heating plant 1 flue gas temperature with 2% increase in excess air | °C |
| $T_{FlueNewHP2}$ | Heating plant 2 flue gas temperature with 2% increase in excess air | °C |
| $T_{FurnHP1}$ | Heating plant 1 furnace air temperature | °C |
| $T_{FurnHP2}$ | Heating plant 2 furnace air temperature | °C |
| $T_{FurnNewHP1}$ | Heating plant 1 furnace air temperature with 2% increase in excess air | °C |
| $T_{FurnNewHP2}$ | Heating plant 2 furnace air temperature with 2% increase in excess air | °C |
| $T_{HEHP1}$ | Heating plant 1 heat exchanger outlet air temperature | °C |
| $T_{HEHP2}$ | Heating plant 2 heat exchanger outlet air temperature | °C |
| $T_{HENewHP1}$ | Heating plant 1 heat exchanger outlet air temperature with 2% increase in excess air | °C |

| | | |
|---|---|---|
| $T_{HENewHP2}$ | Heating plant 2 heat exchanger outlet air temperature with 2% increase in excess air | °C |
| $T_{HHP1}$ | Heating plant 1 heater outlet air temperature | °C |
| $T_{HHP2}$ | Heating plant 2 heater outlet air temperature | °C |
| $T_{in}$ | Inlet fluid temperature | °C |
| $T_{OilInHP1}$ | Heating plant 1 inlet oil temperature | °C |
| $T_{OilInHP2}$ | Heating plant 2 inlet oil temperature | °C |
| $T_{OilInNewHP1}$ | Heating plant 1 inlet oil temperature with 2% increase in excess air | °C |
| $T_{OilInNewHP2}$ | Heating plant 2 inlet oil temperature with 2% increase in excess air | °C |
| $T_{OilOutHP1}$ | Heating plant 1 outlet oil temperature | °C |
| $T_{OilOutHP2}$ | Heating plant 2 outlet oil temperature | °C |
| $T_{OilOutNewHP1}$ | Heating plant 1 outlet oil temperature with 2% increase in excess air | °C |
| $T_{OilOutNewHP2}$ | Heating plant 2 outlet oil temperature with 2% increase in excess air | °C |
| $T_{out}$ | outlet fluid temperature | °C |
| $UA_{HP1}$ | Heating plant 1 heat transfer coefficient x Area | W/°C |
| $UA_{HP2}$ | Heating plant 2 heat transfer coefficient x Area | W/°C |
| VCO | Volume of carbon monoxide, %mol | % |
| $VO_2$ | Heating plant excess oxygen, %mol | % |
| $\Delta T_{HP1}$ | Heating plant 1 log temperature difference | °C |
| $\Delta T_{HP2}$ | Heating plant 2 log temperature difference | °C |

# CONTRIBUTIONS

The major contribution of this thesis has been to apply the technique of carbon monoxide monitoring trim control to a heating plant. While this technique has been known for some time, the implementation using a specific analyser on a PLC (Programmable logic control) controller has not previously been done within New Zealand industry. Specifically, RCR Energy Systems Limited has had no previous experience with carbon monoxide trim control nor carbon monoxide online analysers.

The specific contributions described in this thesis and made by the author, are:

1. A literature review of boiler combustion with regard to production/control of carbon monoxide and excess air,

2. The analysis of carbon monoxide control loop structures leading to a design of one for this project,

3. An analysis of two online, carbon monoxide analysers leading to a choice of one for this project,

4. Implementation of the control loop in the Sequential Function Chart (SFC) and Structure Text programming languages for a PLC control,

5. Implementation of the analyser and control loop on a heating plant in Tumarumba, Australia (with assistance),

6. An analysis of the data from the investigation of the performance heating plants prior to implementing the trim control,

7. An analysis of the operation of the analyser and control loop on the heating plants,

8. An analysis of the mass and heat balances of the heating plants,

9. A financial analysis of the payback period for such control on a boiler plant from historical data.