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IMPROVING HEATING PLANT EMISSIONS USING FLUE GAS CARBON MONOXIDE MONITORING

A thesis presented in partial fulfilment of the requirements for the degree of
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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 Tumberumba, Australia. The tests proved that the excess air setpoint could be successfully reduced by 2%, leading to an approximate 3 – 5% improvement in efficiency.

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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.

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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 1 air 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 2 air 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

$\rho_{OilInHP2Prf}$	Heating plant 2 Perfecto HT12 inlet oil density	kg/m ³
$\rho_{OilInHP2Texa}$	Heating plant 2 Texatherm 32 inlet oil density	kg/m ³
$\rho_{OilOutHP1Prf}$	Heating plant 1 Perfecto HT12 outlet oil density	kg/m ³
$\rho_{OilOutHP1Texa}$	Heating plant 1 Texatherm 32 outlet oil density	kg/m ³
$\rho_{OilOutHP2Prf}$	Heating plant 2 Perfecto HT12 outlet oil density	kg/m ³
$\rho_{OilOutHP2Texa}$	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
$T_{\text{OilInNewHP1}}$	Heating plant 1 inlet oil temperature with 2% increase in excess air	°C
$T_{\text{OilInNewHP2}}$	Heating plant 2 inlet oil temperature with 2% increase in excess air	°C
$T_{\text{OilOutHP1}}$	Heating plant 1 outlet oil temperature	°C
$T_{\text{OilOutHP2}}$	Heating plant 2 outlet oil temperature	°C
$T_{\text{OilOutNewHP1}}$	Heating plant 1 outlet oil temperature with 2% increase in excess air	°C
$T_{\text{OilOutNewHP2}}$	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	%
ΔT_{HP1}	Heating plant 1 log temperature difference	°C
ΔT_{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.