A MACROSCOPIC DETERMINATION OF THE IMPACT OF LETHABO COAL QUALITY UPON THE OPTIMUM COMBUSTION AIR QUANTITY

A MACROSCOPIC DETERMINATION OF THE IMPACT OF LETHABO COAL QUALITY UPON THE OPTIMUM COMBUSTION AIR QUANTITY

Christoffel Philippus Storm

B.Eng (Mech) Hons. (Pretoria)

M.Eng (Mech) (PU for CHE)

A thesis submitted to the Department of Mechanical Engineering of the University of Potchefstroom for Christian Higher Education, in fulfilment of the requirements for the degree of Ph.D. Eng. (Mechanical)

Mentor: Prof. J. P. van der Walt

Potchefstroom
1998

DECLARATION

DECLARATION

I declare that this thesis is my own, unaided work. The deficiencies in the concerned processes and plant were identified by myself, as also the formulation of the philosophies and methodology of testing, as explained in the script. The project leadership throughout and major decision making was exercised by myself. It is being submitted for the degree of Doctor of Science in Engineering (Mechanical) at the University of Potchefstroom for Christian Higher Education, Potchefstroom. It has not been submitted for any degree or examination to any other university before.

____

C P Storm

9th day of JULY 1998

ABSTRACT

ABSTRACT

Lethabo Power Station burns a unique low grade coal with low volatile content. This merits the optimisation of the total combustion air quantity with efficiency as main criterion to produce an air flow - steam flow curve as a function of load as well as coal quality. This project demonstrates the optimisation exercise of the unit as a whole, including the boiler as well as the turbine (a 600 MW turbo-alternator set), therefore producing optimum air flow quantities different to the conventional wisdom. Ninety tests were performed with varying total air flow, at five loads ranging from full load to lowest load with three different coal qualities.

The application of the Station Thermal Efficiency Program (STEP) as optimising tool employs a simultaneous direct and indirect calculation method (opposed to the traditional indirect only methods and programs). The test results were used to customise the targets of the STEP program for Lethabo as well as to introduce new philosophies in the formulae.

The expected trend of higher unit efficiencies with resulting improved total emissions were confirmed. In the process, operational enhancements such as new milling plant settings and sootblowing philosophies were also confirmed to contribute to the improved efficiencies. The findings were operationally implemented which included statutory procedurisation.

DEDICATION

To my wife

Annamie

and children

Karina

Chris

Andrè

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

Gratitude is extended to the University of Potchefstroom for Christian Higher Education and specifically the Department of Mechanical Engineering for accommodating this project. The high level academic influence through the guidance given did justice to the required standard of this thesis.

The support of the Lethabo Power Station manager concerning the provision of the project funds is highly appreciated. His vision and creative long term thinking regarding this project's role in the overall Performance Growth Project of the power station is reassuring for the future standard of power generation.

Appreciation goes to Mr. B. L. Pitman and Dr. M. Van der Riet (Corporate Consultants) for their advice and assistance. Their knowledge and support contributed greatly to the standard of this project.

Special acknowledgement goes to my colleagues, Mr. C. A. Els (STEP program customisation and software calculation) and Mr. A. M. Hattingh (unit outage preparation and pulverised fuel sampling and calculations) in the Plant Efficiency and Optimisation section, for their innovation and hard work.

A word of thanks is extended to all the other departments in ESKOM, Lethabo Power Station and New Vaal Mine for their services in the execution of the test and compiling of the thesis:

- The mining and supply of the coal batches for testing.
- The expert panel operating skills during the tests.
- The preparation of the unit during the preceding general overhaul, as well as the control and instrumentation optimisation.
- All the production and loading arrangements during the tests.
- ESKOM Technology Research and Investigations for the provision and expert service concerning the flue gas measurement with the mobile analytical facility.
- The personnel of the Plant Efficiency and Optimisation section for logistic and administrative support.

All praise goes to Jesus Christ, our Lord and Saviour, without Who's blessing and grace nothing is possible.

CONTENTS

CONTENTS

page

VOLUME I

VOLUME II

page

LIST OF FIGURES

LIST OF FIGURES

VOLUME II

LIST OF TABLES

LIST OF TABLES

LIST OF SYMBOLS

LIST OF SYMBOLS

Quantity	Symbol
Absolute humidity	∞
Acceleration, metres per second squared	ms^{-2}
Aluminium oxide	Al_2O_3
Area	A
Atmospheric or barometric pressure	P_{atm}
Calcium oxide	CaO
Carbon	C
Carbon dioxide	CO_2
Carbon monoxide	CO
Chromium	Cr
Coefficient of discharge (or diffusion)	C_d
Condenser cooling water inlet temperature	T_1
Condenser cooling water outlet temperature	T_2
Condenser hotwell condensate temperature	T_c
Condenser vacuum saturation pressure	P_s
Cubic meters	m^3
Degrees Celsius	°C
Degrees latitude or longitude	°
Density	kg/m^3
Dry bulb temperature	T_{db}
Dynamic, velocity or differential pressure	P_{dyn}
Efficiency	η

Quantity	Symbol
Electric current, Ampère	I
Electric resistance, Ohm (where applicable)	R
Entropy	S
Gravitational acceleration (ms^{-2})	g
Greater or equal than	≥
Greater than	>
Heat flow (when applicable)	Q
Hertz (frequency, cycles per second)	Hz
Hour (when applicable)	h
Hydro-Carbon (type of volatile matter)	C_xH_y
Hydrogen - elemental	H
Hydrogen gas	H_2
Iron oxide	Fe_2O_3
Kelvin (Absolute temperature)	K
Kilogram	kg
Kilojoule	kJ
Kilolitre	kl
Kilopascal	kPa
Kilowatt	kW
Lesser or equal than	≤
Lesser than	<
Lower temperature	T_L
Magnesium oxide	MgO
Manganese oxide	MnO

Quantity	Symbol
Mass flow of the mixture, actual	m_m
Mass flow of the mixture, theoretical (ideal)	m_{mt}
Mass [kg] or mass flow [kg/s] (when applicable)	m
Megajoules per kilogram (Heating value)	MJ/kg
Megapascal	MPa
Megavolt-ampéres reactive power	MVAr
Megawatt	MW
Megawatt-hour	MWh
Metre (when applicable)	m
Micrometre	µm
Milliampere	mA
Milligram	mg
Milligrams per standard cubic metre	mg/sm^3
Millimetre	mm
Minutes latitude or longitude	'
Molecular mass (kg/mole)	M
Nitrogen - elemental	N
Nitrogen gas	N_2
Nitrous oxides	NO_x
Oxygen - elemental	O
Oxygen gas	O_2
Partial pressure of dry air	P_{air}
Partial pressure of the water vapour	P_w
Parts per million (volumetric)	ppm

Quantity	Symbol
Pascal	Pa
Phosphorus penta-oxide	P_2O_5
Polytropic expansion coefficient	n
Potassium oxide	K_2O
Pressure	P
Relative humidity	ϕ
Saturation pressure (in general)	P_s
Seconds (when applicable)	s
Seconds latitude or longitude	"
Silicon dioxide	SiO_2
Silicon oxide	SiO
Sodium oxide	Na_2O
Specific enthalpy (kJ/kg)	h
Specific entropy (kJ/kgK)	s
Specific gas constant (= 287,1 kJ/kgK for air)	R
Specific heat capacity (J/kgK)	c
Specific heat capacity @ constant pressure (J/kgK)	c_p
Specific heat capacity @ constant pressure for air	c_{pa}
Specific heat capacity @ constant pressure for gas	c_{pg}
Specific heat capacity @ constant volume (J/kgK)	c_v
Specific volume	v
Specific volume of dry air	v_{air}
Specific volume of water liquid	v_f
Specific volume of water vapour	v_s

Quantity	Symbol
Square meters	m^2
Stagnation or total pressure	P_{stagn}
Static pressure	P_{stat}
Sulphur	S
Sulphur dioxide	SO_2
Sulphur tri-oxide	SO_3
Temperature	T
Time or tons (metric) when applicable	t
Titanium dioxide	TiO_2
Tons per hour	t/h
Universal gas constant (= 8,314 kJ/moleK)	<u>R</u>
Upper (high) temperature	T_H
Velocity (when applicable)	V
Velocity proportional factor	V-fact
Volume (in e.g. gas equation)	V
Volume flow (when applicable) (m^3s^{-1})	Q
Wet-bulb temperature	T_{wb}

NOMENCLATURE

NOMENCLATURE

Abbreviation	Description
A/F	Air to fuel ratio
A/HTR	Air heater
Aerofoil	Rectangular venturi-type flow measuring device
AFT	Ash fusion temperature
AGC	Automatic generation control
avg	Average
AVR	Automatic voltage regulator
BEC	Babcock Engineering Contractors
BFPT	Boiler feed pump turbine
BMI	Buro vir Meganiese Ingenieurswese
BS	British Standard no.
C&I	Control & Instrumentation (Dept)
CAPCO	Chief Air Pollution Control Officer
CEGB	Central Electricity Generating Board (UK)
Cegrit	CEGB grit sampler, Unburnt carbon in grit (%)
CET	Classifier exit temperature (mill)
CFD	Computational Fluid Dynamics
CT	Current transformer
CV	Calorific value (see MJ/kg)
CW	Cooling water
DAF	Dry ash free
db	Decibel

Abbreviation	Description
DE	Drive end (of a mill)
Dfg	Dry flue gas
DIN	Deutche Industrie Norm
DMS	Dense media separation
DRACAS	Deficiency recording & corrective action system
DSC	Differential scanning calorimeter
DTF	Drop tube furnace
EFP	Electric feed pump
EHC	Electro-hydraulic control (turbine governor valves)
EID	Engineering Investigations Division (now TRI)
EN	European Norm
ENCOR	ESKOM National Control Computer Replacement
EPRI	Electric Power Research Institute (USA)
ESKOM	Electricity utility in South Africa
ESP	Electrostatic precipitators
FD	Forced draught (fan)
FTIR	Fourier transform infra-red retroscopy
GCV	Gross calorific value
GCV_v	Gross calorific value at constant volume
GO	General Overhaul
HIV	Heat in volatiles (percentage)
HP	High pressure (turbine)
HR	Heat rate
i/s	In service

Abbreviation	Description
ID	Induced draught (fan)
IDT	Initial deformation temperature (ash)
IP	Intermediate pressure (turbine cylinder)
IR	Interim refurbishment (type of unit outage)
ISO	International Standard Organisation
LH	Left hand (casing)
LHI	Left hand inner (casing)
LHO	Left hand outer (casing)
LP	Low pressure (turbine cylinder)
m.a.s.l.	Metres above sea level
MAN	Maschinenfabrik Augsburg Nürnberg (Turbine supplier)
MCR	Maximum continuous rating
MHC	Mechanical-hydraulic control (turbine governor valves)
MIDAS	On line computer logging electrical energy
NCV	Nett calorific value
NCV_p	Nett calorific value at constant pressure
NDE	Non-drive end (of a mill)
NMR	Nuclear magnetic resonance
NTP	Normal temperature and pressure (25 °C, 1 atmosphere)
o/c	Out of commission
OPCR	Outside plant control room
OPS Log	Operational log kept by unit shift supervisor
P/A/HTR	Primary air heater
PA	Primary air: that portion of total air transporting pf

Abbreviation	Description
PC	Personal computer
PEO	Plant Efficiency and Optimisation (section)
PEPSE	Performance Evaluation of Power Station Efficiencies
Pf	Pulverised fuel (coal)
PGP	Performance Growth Project (Management System)
ppm	Parts per million
RC	Reactivity cell
Rev.	Revision
RH	Right hand (casing)
RHI	Right hand inner (casing)
RHO	Right hand outer (casing)
ROI	Return on investment (financial)
ROM	Run of Mine
rpm	revolutions per minute
RWE	Rheinisch Westfälische Elektrizitatswerke
S/A/HTR	Secondary air heater
SA	Secondary air: with primary air, makes up total air
SFP	Steam feed pump
Spec.	Specified quality, contractual specification
SSC	Submerged scraper conveyor (in ash hopper)
STEAG	Steinkohlen Aktien - Gesellschaft
STEP	Station Thermal Efficiency Performance
STP	Standard temperature and pressure (0 °C, 1 atmosphere)
TGA	Thermo-gravimetric analysis

Abbreviation	Description
TH	Transfer house (stockyard and coal supply)
TRI	Technology Research and Investigations (previously EID)
UCI	Utlility Consultants International GMBH
UG	Units generated (electrical energy)
Unit	Boiler and turbogenerator combination
USO	Units sent out (electrical energy)
U1	Unit 1
U_2	Unit 2
VDU	Visual Display Unit (screen in control room)
VGB	Vereinigung der Grosskessel Betreiber
VT	Voltage transformer
WA	Work authorisation