Analysing Fly-Ash Erosion in Coal-Fired Boilers using Computational Fluid Dynamics

BY

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Summary

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Boiler tube failure due to fly-ash erosion is a major cause of forced outages of boiler plants worldwide. This problem is exacerbated in Southern Africa because of the high quartz (SiO_2) content in the coal. Specifically, Babcock boilers at Sasol in Secunda suffer from fly-ash erosion, especially in the convection pass where the ash temperatures are below 1100K and the ash no longer has the propensity for the formation of adhesive deposits.

The first part of this study is an extensive literature survey on boiler operation, tube failures caused by erosion and erosion-oxidation, and remedial measures for boiler tube failures. Flow in tube banks as well as CFD modelling of erosion and boiler flow are included in the literature survey.

The second part of this study concentrates on the simplification of the CFD modelling of the boiler. STAR-CD is used as the CFD solver in this study. As combustion is not modelled, the burner geometry is simplified and the burners are 'replaced' with hot air, seeded with fly-ash particles. In this simplification, the effect of the location of the burner/boiler inlets on the global flow patterns in the boiler is investigated. Methods to simplify boiler internals such as the boiler bank and airheaters are also investigated. Porous sections, of which the porosity is obtained by a detailed CFD hydraulic model of these elements, replace the boiler bank and airheaters.

In the third part of this study, remedial measures for boiler tube erosion in the Babcock boilers are investigated. The areas where erosion occur is at the superheater tubes near the top of the boiler, and in areas where there are larger than usual tube spacings. The remedial measures used in this dissertation are flow-modifying approaches through the use of baffles and tube fins. The remedial measures are applied with success to reduce peak velocities and high fly-ash particle concentration in regions of high erosive wear.

This study is successful because all the requirements of remedial measures for boiler tube failures were met. Boiler CFD models were successfully simplified by using a uniform boiler inlet geometry and 2D models. The effect

of boiler internals such as the tube bank can be omitted in boiler CFD models for erosion studies in the upper boiler. This leads to simple inexpensive CFD models that significantly reduces solution time.

Key words:
Computational Fluid Dynamics
Boiler Tube Failures
Erosion
Remedial Measures
Flow-Modifying Devices
Superheater Tubes
Bullnose
Two-Phase Flow
In-Line Tube Bank
Porosity
Model Simplification

Samevatting

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Stoomketelbuisfalings as gevolg van vliegas is een van die hoofoorsake van onbeplande afsluitings van ketelaanlegte wêreldwyd. In Suidelike Afrika word die probleem vererger deur die hoë kwartsiet (SiO_2) inhoud van die steenkool. Meer spesifiek, die Babcock ketels by Sasol Secunda ondervind vliegas erosie, veral in die konveksie gedeelte waar die astemperature onder 1100K daal en die as nie meer 'n geneigtheid het om klewerige nedersettings te vorm nie.

Die eerste gedeelte van hierdie studie is 'n uitgebruide literatuurstudie van ketelwerking, buisfalings veroorsaak deur erosie en erosie-oksidasie, en metodes om buisfalings te verminder. Vloei in die konveksie buisbank en Berekeningsvloeidinamika (BVD) modellering van erosie en ketelvloei is ingesluit in die literatuurstudie.

Die tweede deel van hierdie studie konsentreer op die vereenvoudiging van BVD ketel modellering. STAR-CD word gebruik as die BVD oplosser in hierdie studie. Omdat verbranding nie gemodeleer word nie, word die verbranders 'vervang' deur warm lug waarin vliegas partikels vrygestel word. In hierdie vereenvoudiging word die effek van die posisie van die verbrander/ketel inlaat ondersoek op die globale vloeiveld in die ketel. Metodes om die interne buise in die ketel te vereenvouding word ook ondersoek. Poreuse gedeeltes, waarvan die porositeit verkry word deur deur 'n gedetaileerde hidrouliese model, vervang interne buise van die ketel.

In die derde gedeelte van hierdie studie word metodes ondersoek om ketelbuisfalings te voorkom. Die gebiede waar erosie in die ketel voorkom is by die oorverhitte stoombuise naby die bopunt van die ketel, en in die gebiede waar daar groter as gewoonlik gapings tussen die buise is. Die metode wat gebruik word om die falings te verhoed is die vloeimodifiserings benadering deur gebruik te maak van keerplate en buisvinne. Hierdie metode word met sukses toegepas om hoë pieksnelhede en hoë partikel konsentrasies te verminder om sodoende erosie te verminder.

Hierdie studie is suksesvol afgehandel omdat metodes gevind is om ketelbuis erosie hok te slaan. Ketel BVD modelle is suksesvol vereenvoudig deur gebruik te maak van uniforme inlaat geometrieë en 2D. Die effek van die interne buise in die ketel kan uitgelaat word waar ketel BVD modelle vir erosie studies in die boonste gedeeltes van die ketel gebruik word. Al die vereenvoudigings lei tot eenvoudige, goedkoop BVD modelle wat relatief vinnig oplossings verskaf.

Sleutelterme:
Berekeningsvloeidinamika
Ketel Buisfalings
Erosie
Remediërende maatstawwe
Vloei Modifiseringstoestel
Oorverhitte Buise
Bulneus
Tweefase vloei
Inlyn Buisbank
Porositeit.
Model Vereenvoudiging

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Table of Contents

List of Symbols

English Symbols

D	Diameter of tube
E	Internal energy
f	Friction factor
g	Acceleration of gravity
h	Enthalpy
J	Jacobian of transformation
k	Thermal conductivity; Turbulence kinetic energy
L	Characteristic length
N_L	Number of tube rows in tube bank
p	Pressure
P	Control parameter, Eq. (2-5)
P_L	Relative longitudinal pitch; S_L/D
P_T	Relative transverse pitch; S_T/D
Q	Control parameter, Eq. (2-5)
S_L	Longitudinal pitch of bank of tubes
S_T	Transverse pitch of bank of tubes
t	Time
T	Temperature
u,v,w	Cartesian velocity components
u',v'	Turbulent velocity fluctuations
V	Velocity
x,y,z	Cartesian coordinates

Greek Symbols

α	Metric coefficient, Eq. (2-5)
β	Metric coefficient, Eq. (2-5); Angle of incidence, Eq. (4-1) and (4-2)
χ	Correction factor
ε	Erosion rate [$mg.g^{-1}$]; Turbulent dissipation
λ	Second viscosity coefficient; Metric coefficient, Eq. (2-5)
η	Computational domain coordinate, Eq. (2-5)
μ	Dynamic viscosity
ρ	Density
τ_{ij}	Stress tensor
τ	Boundary layer shear stress
ξ	Computational domain coordinate, Eq. (2-5)

Dimensionless Groups

Eu	Euler number; $\Delta p/\rho u_0$
Re	Reynolds number; $\rho VL/\mu$

Subscripts

0	Conditions of main flow
L	Longitudinal
N	Normal
t	Turbulent
T	Tangential, transverse

Superscripts

n	Velocity exponent of erosion (Section 3.3.3.1.1)