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Effect of air ingress on the energy performance of coal fired thermal power plants

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Abstract

Ingress of air in boilers leads to drops in energy efficiency. This paper presents the effects of air ingress in the combustion zone, post-combustion zone and air pre-heater (APH) on the energy efficiency and loading capacity of a coal fired thermal power plant operating on fuel with high ash (35–45%). The optimal O_2 in the flue gas for a pulverized coal fired system is 3.5% (corresponding to 20% excess air). The operating values are in the range of 4.2–6.0% in membrane type boilers and up to 10% in refractory type boilers (after sustained periods of operation). The leakage rate of boilers (up to the entrance of the APH) is designed at 0.2% while the average operating values are 7.25% for membrane type enclosures and 33.61% for refractory enclosures. The leakage rate of the APH is designed at 5.0% while the operating values range from 13.66% to 20.13% for rotary and tubular APHs. When the O_2 in the combustion zone varies from 3.5% to 8.0%, efficiency drops of 2.0% points are experienced in the boiler and turbine separately, and the gross overall efficiency drop is ~3.0% points. The units do not experience any capacity drop up to an O_2 in the flue gas of 6.0% before the APH. At an O_2 in the flue gas (before APH) of 7.2%, a mild limitation on the unit capacity of around 2–3% is experienced. When O_2 in the flue gas (before APH) reaches a level of 9.0%, 20% capacity drop of the unit is experienced due to which the plant load cannot be raised higher than 80%. Beyond the level of 9.0% (rare occurrence), the unit is quite difficult to operate and has to be taken off for overhaul.

Keywords: Air ingress; O_2 in flue gas; Excess air; Rotary air pre-heater; Membrane type water walls; Capacity factor; Boiler efficiency; Gross overall efficiency

1. Introduction

Infiltration of air in the boiler and internal leakage of air in the air pre-heater are operating problems in many coal fired thermal units, especially those using fuels with high ash (35–45%), and affect their energy efficiency and loading capacity. The high ash in coal leads to acceleration of wear and erosion of internal components, which affect the air tightness.

Coal boilers perform the dual role of combustion of fuel and transfer of heat to the working fluid, viz. water-steam. The combustor is designed for air supply as:

- Primary air during pulverization and to heat and convey the coal from the bunker to the combustor.
- Secondary air injection in the boiler to provide the temperature and turbulence required for effective combustion of fuel.

The total air supply (primary and secondary air) is the theoretical air (stoichiometric) plus an optimal quantity of excess air (20% for pulverized coal combustion, 5% for liquid fuels and 3% for gaseous fuels) [1]. The excess air is based on the hydrodynamic efficiency of intimate mixing of coal and air streams and is a measure of the inhomogeneity of mixing. If the mixing of air with fuel does not take place, the unmixed air acts as a dilutant without any useful purpose and only enhances the largest energy loss in the boiler, viz. the dry flue gas loss.

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Nomenclature

$A_0, \ldots, A_2$	constants in curve fits
AFR	air to fuel ratio (dimensionless: 4–6 for coal)
APH	air pre-heater
B_0, B_1	constants in curve fits
C	calorific value (MJ/kg)
CF	capacity factor (dimensionless: 0–1; 0–100% of MCR)
CO/CO_2	Carbon monoxide/dioxide (volumetric percentage in flue gas)
d	tube diameter or transverse spacing (mm)
D_0, D_1	constants in curve fits
E	erosion rate (mm/h)
f	fraction
FD	forced draft
ID	induced draft
MCR	maximum continuous rating (MW)
N_2	nitrogen (volumetric percentage in flue gas)
O_2	oxygen (volumetric percentage in flue gas)
p	pressure (Pa, kPa or MPa)
P	power input/output (MW)
PA	primary air
Q	rate of heat addition (MW_t)
R^2	measure of approximation of curve fit to data points. Predictive power of curve fit to related data points
SEC	specific energy consumption (kW h t^{-1})
SECR	specific energy consumption ratio (dimensionless: 1.0–2.0)
T	temperature (°C)
t	time (h)
v	velocity (m s^{-1})
VR	velocity ratio (dimensionless: 0.8–5.0)
X	independent variable
Y	dependent variable

Greeks

α	excess air factor (dimensionless: 1.0–3.0)
δ	leakage rate (dimensionless: 0–1.0)
Δ	difference
η	efficiency (dimensionless or %)

Subscripts

a	ambient
av	average
A	auxiliary
B	boiler
BA	bottom ash
e	electric
f	flame
G	generator
in	input
m	mechanical
max	maximum
O	gross overall
ref	reference
S	steam
T	turbine

On the other hand, if the excess air is below the optimal level by over 2% points (i.e., from 20% excess air to 18% excess air for coal combustion), it can lead to excessive production of CO (due to O_2 deficient carbon conversion), increased risks of explosion (release of CO and H_2), slag build-up and fouling in the post-combustion zones (due to temperatures in these zones exceeding the ash fusion temperatures).

Earlier trends in minimizing excess air to their thread bare levels led to unusually high levels of NO_x. The NO_x in flue gas increased by 35% for a decrease of excess air from 20% to 10% for coal [2,3]. Present trends are to keep the excess air to the barest level satisfying a guaranteed minimum NO_x and minimum SO_2 to SO_3 conversion [4].

Injection of a higher quantity of primary air than required results in mill wear (due to recirculation of coal–air mixture), higher erosion of pulverized piping (due to higher flow velocities), combustion difficulties (due to lean primary air to fuel ratio), higher pressure drop, increased auxiliary power, higher primary fuel jet velocity at the burner tip (resulting in shifting of flame front away from the burner) and difficulty in flame scanning and sensing.

Injection of higher than the required quantity of secondary air is utilized when the fuel is wet or when the unburned carbon level in the ash is high. In such cases, when excess secondary air is injected, the flue gas temperature is increased up to ~10% (due to intensification of combustion) beyond which it decreases (due to dilution of the combustion environment).

The minimum quantity of air required for combustion (stoichiometric air with a design excess air factor) is the technical air requirement for the process. Air is injected at a pressure higher than atmospheric (1–2 kPa; operating tolerance: ±0.2 kPa) and at high temperature (300–350 °C; operating tolerance: ±20 °C). The entrance of air in the ambient mode without design is generally termed as illegal ingress, tramp air, infiltration, etc. This air, which enters the combustor or boiler, is ambient air and does not in any way aid the process of combustion or heat transfer but instead acts as a hindrance in achieving the objective function of the boiler processes. Its entry is mostly in the post-combustion zone, and even if it enters the combustion zone, it will not be in a position or location where it can interactively be involved in the combustion process. While excess injection of quality air from the primary and secondary air fans can be