Central Power Research Institute

Vol. 20(2)/177-180, December 2024
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v20i2.1175

Power Research

Computation of Air-Ingress in Air-Preheater

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Abstract

Air leakage in the flue gas pathway of the air preheater is a significant issue in thermal power plants. It contributes to increased auxiliary power consumption in the Induced Draft (ID), Primary Air (PA), and Secondary Air (SA) fans. Direct measurement of air leakage is challenging; therefore, an indirect method is employed that measures oxygen levels across the device to calculate air ingress. This article derives the equation for air ingress based on the principle of mass conservation. A case study is presented to demonstrate the application of this method in calculating air ingress in the Air Preheater (APH) and the flue gas duct of a thermal power plant.

Keywords: APH, % Air Leakage, O_2 Measurements

1. Introduction

In India, coal-fired thermal power plants produce most electrical energy, accounting for 46.61% of the total energy mix[1]. Although there is a growing trend towards generating power from renewable sources, thermal power plants remain the primary producers of electricity. In these thermal power plants, a portion of the electricity generated is used internally to operate essential auxiliary systems, such as cooling water pumps, PA fans, SA fans, ID fans etc. The auxiliary power consumption varies depending on the plant size, ranging from 5.2% in a 500 MW plant to 12.3% in a 30 MW plant[2]. Effective operation of the high power-consuming auxiliaries is essential to keep the auxiliary power consumption within the desirable limits. APH is such a component among the auxiliaries which affects the overall plant performance and the energy consumed by bigger auxiliaries like PA fans, SA fans and ID fans. The placement of APH in the flue gas path in a balanced draft boiler is shown in Figure 1. Most boilers operate using a balanced draft system, where the pressure in different parts of the boiler is collectively maintained by the PA, Forced Draft (FD), and ID fans. To prevent fire hazards, the area of the boiler leading up to the ID fan is kept under a vacuum[3].

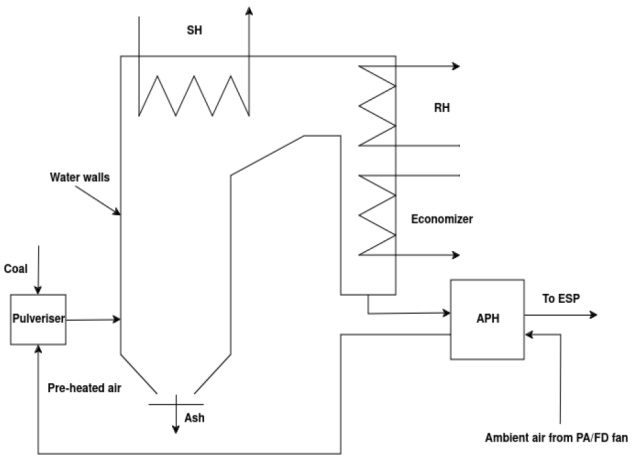


Figure 1. Block diagram of boiler with air and flue gas path.
SH: Superheater, RH: Re-Heater
APH: Air Preheater
ESP: Electrostatic Precipitator

In a boiler, an APH preheats incoming atmospheric air by using the heat of flue gases leaving the economizer. Regenerative air preheater is one of the largest heat recovery systems in thermal power plants[4]. Nowadays, a tri-sector rotary APH is commonly used, which simultaneously preheats both primary and secondary air within a single unit. Typically, the pressure on the air side is significantly higher than that of the

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flue gases, since vacuum is maintained in flue gas path in most of the power plants. To prevent air from leaking into the flue gases, three types of seals are employed: axial seals, peripheral seals, and radial seals[5]. Before addressing any leakage issues within the system, it is crucial to estimate the percentage of leakage in various components and pathways. Leakage in the APH or duct can result in financial losses, making it necessary to quantify the leakage at different components before taking the necessary actions to address it.

R. Mandi *et al.*[2] discuss various opportunities to reduce the auxiliary power consumption of ID fans. B. Drobic *et al.*[5] presented a numerical model for analysing heat transfer and leakage in rotary air preheaters. Based on their findings, they propose online monitoring of radial seals to minimize leakage. A. Maharaj *et al.*[6] conducted a numerical study to quantify direct leakage from a Ljungstrom air preheater using a 2D Computational Fluid Dynamics (CFD) model. X. Zhang *et al.*[7] developed a model to estimate direct leakage in rotary air preheaters based on temperature distribution. In AMSE PTC 4.1[8], an empirical equation for leakage in APH is provided, expressed in terms of CO_2 levels on both sides of the device. In this article, we derive an equation for direct air leakage in the APH based on oxygen levels measured on either side of the device using a gas analyser.

Section II provides an overview of the development of mathematical modelling. Section III includes the implementation of the presented mathematical model using the data obtained during an Auxiliary Power Consumption (APC) audit study conducted at Koradi Thermal Power Station (3 × 660 MW). This case study estimates air leakage in the air preheater and in the duct extending from the air preheater outlet to the ID fan inlet, followed by the conclusion.

2. Mathematical Modelling of the APH

Consider a general device in the flue gas path, as shown in Figure 2, where flue gas exchange occurs. In this case, it is an air preheater. The flue gas with mass flow rate O_1 and having volumetric oxygen percentage O_1 enters the device at (1). The flue gas leaves the device at (2) with mass flow rate O_2 and oxygen percentage O_2. This oxygen percentage can be measured directly using a flue gas analyser. As the flue path is maintained at negative gauge pressure, some amount of air will always leak through the device and into the duct. Let O_3 be the mass flow rate of outside atmospheric air leaking through the device having volumetric oxygen percentage O_3.

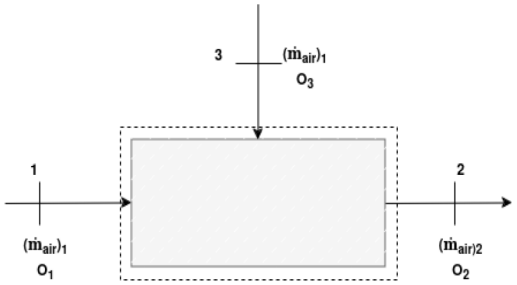


Figure 2. A device in flue gas path

The principle of conservation of mass is a universal concept. From this principle, we can derive volume conservation; however, it only applies when the flow is incompressible. This condition is rarely met with gases. Therefore, in the case of air and oxygen in APH, it is more appropriate to use the principle of conservation of mass. In the device being examined, this principle applies separately to the air and oxygen streams.

Applying the conservation of mass (of air) principle,

$$\dot{m}_2 = \dot{m}_1 + \dot{m}_3 \ldots..(1)$$

Similarly, applying the conservation of mass (of oxygen) to the device,

$$\left(\dot{m}_{O_2}\right)_2 = \left(\dot{m}_{O_2}\right)_1 + \left(\dot{m}_{O_2}\right)_3 \ldots\ldots.(2)$$

Now, oxygen in the flue gas obeys the ideal gas equation[9]. Therefore,

$$\frac{O_2 P_2 \dot{V}_2}{R_o T_2} = \frac{O_1 P_1 \dot{V}_1}{R_o T_1} + \frac{O_3 P_3 \dot{V}_3}{R_o T_3} \ldots(3)$$

Where,

O_1 : Percentage of oxygen (on a volume basis) in the flue gas at the inlet (1)

R_O : Specific gas constant of oxygen,

Other terms have their usual meanings.

Now, for ideal gases,

$$P\dot{V} = \dot{m} R_{air/flue} T$$

Put this in Equation (3),

$$\frac{O_2 \dot{m}_2 R_{f2}}{R_O} = \frac{O_1 \dot{m}_1 R_{f1}}{R_O} + \frac{O_3 \dot{m}_3 R_{f3}}{R_O} \ldots(4)$$

Using Equation (1) and simplifying,

$$O_2 R_{f2} \left(\dot{m}_1 + \dot{m}_3\right) = O_1 R_{f1} \dot{m}_1 + O_3 R_{air} \dot{m}_3$$

Therefore, the air leakage in the device is given by:

$$\dot{m}_3 = \left[\frac{O_2 R_{f2} - O_1 R_{f1}}{O_3 R_{air} - O_2 R_{f2}}\right] \dot{m}_1 \ldots\ldots (5)$$

As R = R_u /M, (where M = molecular weight of a gas), then the above equation becomes:

$$\dot{m}_3 = \left[\frac{\frac{O_2}{M_{f2}} - \frac{O_1}{M_{f1}}}{\frac{O_3}{M_{air}} - \frac{O_2}{M_{f2}}}\right] \dot{m}_1 \ldots..(6)$$

This is the equation for air leakage into the device or a duct of a particular length across which the oxygen level in the flue gas is known. For determining the absolute value of air leakage, the base mass flow rate of flue gas at entry must also be known. The % leakage that takes place in the device becomes:

$$\%\ air\ ingress = \frac{\dot{m}_3}{\dot{m}_1} = \left[\frac{\frac{O_2}{M_{f2}} - \frac{O_1}{M_{f1}}}{\frac{O_3}{M_{air}} - \frac{O_2}{M_{f2}}}\right] ..(7)$$

3. Results and Discussions

In the auxiliary power consumption study of 3 × 660 MW of Koradi Thermal Power Plant, the volumetric % of oxygen in one of the units (#8) at various points, was measured with a flue gas analyser as shown in Table 1.

Table 1. % of oxygen level at various points

	LHS	RHS
APH inlet	2.80	3.07
APH outlet	4.66	5.00
ID Fan inlet	8.57	8.57

As per Equation (7), the knowledge of the molecular weight of flue gases at (1) and (2) in Figure 2 is necessary. This value is calculated using ultimate analysis of the coal with some assumptions as follows. The ultimate analysis of the design coal for the plant is as given in Table 2.

Table 2. Ultimate analysis of design coal

	C	H_2	S	O_2	N_2
% by mass	40.34	2.61	0.8	10.64	0.97

Assuming complete combustion with 10 % excess air and no NOx formation, the proportion of gases in the exhaust for the design coal are as given in Table 3.

Table 3. Proportion of gases in exhaust at furnace outlet

	CO_2	H_2O	SO_2	O_2	N_2
% by mass	3.74	5.33	0.1	18.02	62.80

Therefore, the molecular weight of the exhaust gas comes as[10]:

$$M_f = (3.74 \times 44 + 5.33 \times 18 + 0.1 \times 64 + 18.02 \times 32 + 62.80 \times 28) / (3.74 + 5.33 + 0.1 + 18.02 + 62.80)$$

$$= 30.42 \frac{kg}{kmol}$$

The proportion of elements in the coal varies along with % of excess air used. Therefore, the nearest integer value of 30 kg/kmol is being used as a molecular weight for all the flue gases.

The corresponding % leakage on a mass basis is computed and shown in Table 4. Specific energy consumption for ID fans is known through knowledge of flue gas flow rate and power consumption. Multiplying the excess leakage in APH and duct gives the scope for power saving in ID. The air from the PA fan and FD fan is also lost to the flue gas path, therefore arresting this leakage promises energy savings for these fans.

Table 4. % leakage of air

	LHS	RHS
In APH	10.95	11.59
Induct from APH outlet to the ID fan inlet	29.90	27.30

4. Conclusion

In this article, the mathematical modelling of air leakage in a device has been derived. While the equation can be applied to any general device or duct, this study focuses specifically on APH, where air ingress is a significant concern. Before implementing remedial measures, it is essential to accurately assess the percentage of leakage in the system and its economic impact on auxiliary power consumption.

The mathematical formulation is based on the measurement of oxygen levels within the device and employs

the principle of conservation of mass. Through ultimate analysis of the design coal, the probable molecular weight of the flue gases has been computed. This formulation is applied to a unit of a thermal power station, where oxygen levels were measured at various points during a field visit for an energy audit. Although the derivation is precise, its accuracy largely depends on the reliability of the measured oxygen levels and an understanding of the flue gases involved.

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