SIMULATION AND NUMERICAL ANALYSIS IN THE SEALING SYSTEM OF THE ROTARY AIR PRE HEATER

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Abstract

Air preheaters make a considerable contribution to the improved overall efficiency of fossil-fuel-fired power plants. In this study the use of a Ljungstrom Air Preheater is analysed for heat transfer as the basis for a theoretical analysis of a rotary air preheater. model enables studies of the flue-gas flow through the preheater and the adjoining channels as well as the The regenerative heat transfer and the resulting temperature distribution in the matrix of the preheater. Special attention was focused on the influences of leakages on the flue-gas parameters in the preheater. The numerical analysis and the experimental results showed an obvious dependence of the flue-gas parameters on various seal settings. Based on the results a soft touch seal with the diaphragm is proposed. And the double seal setting is preferred.

KEYWORDS : *Ljungstrom air preheater, Seals, Corten material, double sealing.*

1. INTRODUCTION

High efficiency is the key feature in the operation of any energy-conversion device, and this includes large fossil fuel- fired steam boilers. It is therefore very important to recover as much energy as possible from that available in the fuel. Air preheaters have proved to have an important influence on the efficiency of the entire steam boiler. Their primary task is to return considerable amounts of waste heat, carried by the flue gas, back to the combustion process. Due to their compactness and high performance, rotary regenerative air preheaters are very common in fossil-fuel-fired steam boilers. Following the development in the boiler technology in recent years, the pressure difference between air and the flue gas has increased in some typical utility boilers and in some specially designed boilers, such as the circulating fluid bed boiler (CFB), where the pressure in the air side can reach from 20 kPa to 25 kPa, However, in ordinary pulverized-coal boiler, the air pressure is usually less than 5 kPa. Under the above conditions, the leakage ratio is usually quite large if only traditional technologies are used in the rotary air preheater seal system. Rotary preheaters have a specific operating principle where the heat is transferred from the flue gas to the air by means of a rotating matrix. A significant weakness of this type of heat exchanger is the unavoidable leakages between both streams caused by the pressure difference between the streams and by the rotation of the matrix. For a large-diameter rotary air preheater, the rotors can be partitioned into many sectors by using more radial diaphragms. Consequently, the triple-seal can save a large seal zone and prevent additional pressure drop. Therefore, multiple-seal technology is widely used in new designs of modern air preheaters.

However, a problem arises because most designers still follow the traditional calculation methods to calculate the direct leakage by modifying the results from the theoretical calculations using certain modifying factors based on the test data. From the practical viewpoint, using structures with multiple seals, such as double or triple, is the main method used in reducing air leakage to cope with the high pressure difference between the air and the flue gas. At the same time there is a need for the constant monitoring of the seals' settings in order to ensure their optimum operation under various working conditions. An efficient sealing system is therefore a pre-requisite for the high performance of an air heater and, consequently, the high efficiency of the steam boiler. The main side effect of the leakage is the need for larger flow rates of air entering the heater and, consequently, larger flow rates of flue gas exiting the heater. The increased flow rates also require more ventilation power. The method is based on the results of numerical simulations. A numerical method was developed that makes it possible to simulate the operation of the rotary air preheater, including the influences of various seal settings on the properties of the flue gas after the preheater. The numerical results were confirmed by measurements.

In the present study, the direct leakage in air preheaters with multiple seals is studied through model tests and numerical simulations, which is aimed at updating the estimation of the orifice coefficient and the modifying factor in a wider range of the inlet pressure and gap size to improve the accuracy of the relevant engineering calculations. Originally some air preheater manufacturers tested the air leakage flux in small wind tunnels. The results suggested that the value of the orifice coefficient to correct the theoretical calculation conformed to that derived from the Bernoulli equation. Although the orifice coefficient in these tests varied within a certain range, to simplify the engineering design, the recommended coefficient was still 0.65, a constant that is independent of the gap size and pressure difference. In these tests, some narrow slots were used to simulate the seal gaps; thus all leaked air passed though the slots without any other air leak path. However, according to practical experience, some other leak paths exist in actual air preheaters. Therefore, a modifying factor (with a value >1) is usually used to correct the extra air leakage effect. Similarly, for simplification, this factor is usually regarded as a constant. This approximation method is only suitable for simple designs with single or double seals with small gap size. For air preheaters with other structures, recent site tests have shown that a large deviation exists between the calculated and experimental results. Consequently, new estimation methods of the orifice coefficient and novel modifying factors for multiple-seal structures are necessary.

2. LEAKAGES IN ROTARY HEAT EXCHANGERS

The basic element of a rotary heat exchanger's operation is a rotating matrix in a compact casing that transfers the heat from the hot flue gas to the cold combustion air. The rotation of the matrix requires an appropriate sealing system to prevent mixing of the flue gas and the air, commonly referred to as leakage. The importance of sealing and leakage and its influence on air-preheater performance was studied by several authors. MacDuff and Clark, for example, present an overview of radial sealing systems

- A lot of research was carried out on the study of influence of leakage on a heat exchanger's performance.
- It also presented methods for calculating the mass flows of gas through the seals
- A method of measuring and adjusting the seal clearances in radial seals
- The irreversibility caused by leakage
- The general conclusion is that the sealing system is an important part of a rotary heat exchanger. Although the leakages in the air preheater do not significantly affect the boiler's overall thermal efficiency
- Excessive leakages can reduce the effectiveness of the air preheater itself by over 10%

At the same time, leakages require more air to be transported to the preheater and more flue gas to be transferred from the preheater, and larger quantities of gases require more power for the air and flue-gas fans.

These fans typically use up to 1.5% of all the power produced. An increased amount of power required for the fan results directly in a noticeable drop in the power plant's overall efficiency. It is therefore important to pay special attention to the adjustment of the seals and to monitor their tightness.

Radial and axial seals reduce the amount of air that is leaking into the flue-gas channel. Typically, the pressure on the air side is considerably higher than the pressure of the flue gas: the difference can reach several thousand Pa. Peripheral seals, on the other hand, prevent the bypass flow of air or flue gas around the matrix. This flow does not contribute to the heat exchange and should also be reduced. Mass flow rates through the peripheral seals are relatively small since the pressure gradients in the axial direction are much smaller than the pressure difference between the hot and cold gas streams.

The axial seals are usually several times shorter than the radial seals, so the majority of the gas is expected to pass through the radial seals. Both the radial and axial seals are adjustable. During start-up or after changing the boiler's load the rotor is deformed due to temperature differences at the hot and cold ends of the rotor. The seals need to be adjusted after any change in the temperature conditions in the exchanger.

Therefore, a suitable means of monitoring the sealing quality should be provided. In rotary heat exchangers another type of leakage occurs, i.e., carry-over leakage. This carry-over leakage means there is always some gas, hot or cold, caught within the matrix's empty space as it moves from one stream to another, which means it is transferred to the opposite stream. The carry-over leakage can be reduced by an appropriate design of the air preheater and the adjoining air and flue-gas channels.

3. PERFORMANCE EVALUATION

3.1. System simulation and main assumptions

The thermodynamic cycle and energy equilibrium of these two based on the coal-fired power plant are simulated. The software should be based on basic physics and conserves the energy and mass balance of all power plant processes. The software also includes an important database that can help to directly calculate the thermodynamic state of the power generation system and can therefore be used for simulating plant conditions at various loads with a high degree of fidelity. The simulation results of these studies are in accordance with the design parameters of the plant and the experimental data. To ensure the precision and reliability of the simulation results, selecting the accurate method and block models is essential. The simulation is approached as a small variation around the nominal conditions of operation allowing the following assumptions simplified:

- For the different stages of the high-pressure (LP), intermediate pressure (IP), and low-pressure (LP) turbines, the isentropic efficiencies are constant and equal to 0.87, 0.92, 0.89 and respectively.
- A constant amount of fuel input and main steam flow rate are chosen for modeling the WHRS integrated with a thermodynamic cycle. The additional power output and improvement in net efficiency are achieved by saving extraction steam.

These hypotheses allow estimating the reduction in steam extraction rate by re-calculation the energy balance of the RH when a part is substituted by the flue gas sensible heat. Constant pressure and turbine extraction temperature are implied. In fact, the saved extraction steam will influence the extraction pressure and temperature in the steam turbine. However, the mass flow of the saved extraction steam is so minute excursions compared with the main steam flow rate, thus in this paper the fluctuation of the extraction pressure and temperature are neglected.

3.2. Leakage analysis

Taking into consideration all these factors and with the measurements available, various reading were taken for assessing RAPH performance and they are as follows. During the study, the operating parameters like pressure, temperature and oxygen percentage along the flue gas path has been carried out. The study was conduct to analyze the performance of air heater and air ingress in the air heater.

DESCRIPTION	DIFFERENTIAL PRESSURE (mbar)		FLUE GAS TEMPERATURE [^{O}C]	OXYGEN (%)
	GAS SIDE	AIR SIDE		
RAPH – I INLET	3.9	26.9	310	3.93
RAPH – I OUTLET	3.5	22.3	170	4.5
RAPH – II INLET	3.9	26.8	316	3.82
RAPH – II OUTLET	3.5	22.4	190	4.85

3.3. Theoretical Calculation

1. Air leakage in preheater is determined by an empirical approximation as following.

$$AL = \frac{(CO_2\,ge - CO_2gl)}{CO_2\,gl} \times 0.9 \times 100$$

AL = air heater leakage (%)

CO_2ge = percent CO_2 in gas entering air heater

CO_2gl = percent CO_2 in gas leaving air heater

CO_2 measurement is preferred due to high absolute values; In case of any measurement errors, the resultant influence on leakage calculation is small. Alternatively, the air heater leakage may also be determined from the following equation:

The numerical average of the air heater's gas inlet, gas outlet and air inlet temperatures is calculated. Then the corrected air heater gas outlet temperature is calculated using the following formula.

$$T_{gnl} = \frac{AL \times C_{pa} \times (T_{gl} - T_{ae})}{C_{pg}} + T_{gl}$$

Tgnl = Gas outlet temp corrected for no leakage

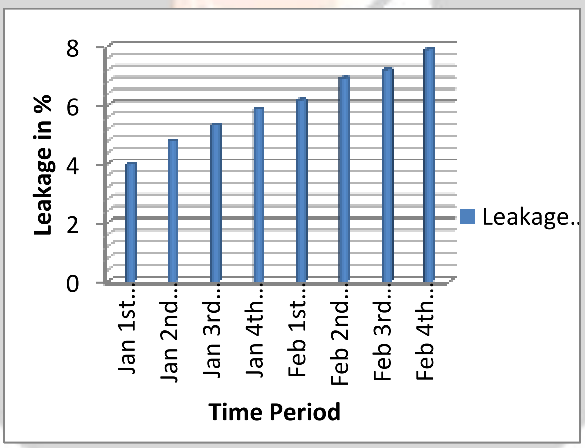
Cpa = The mean specific heat b/w Tae and Tgl

Tae = Temperature of air entering reheater

Tgl = Temperature of gas leaving reheater

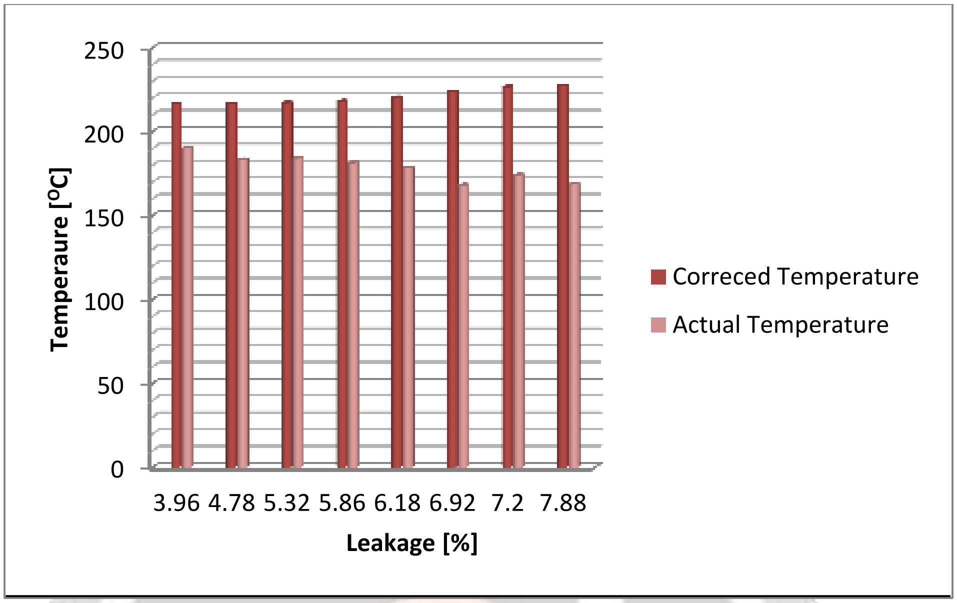
S.NO	TIME PERIOD	LEAKAGE (%)
1	Jan 1st week	3.96
2	Jan 2nd week	4.78
3	Jan 3rd week	5.32
4	Jan 4th week	5.86
5	Feb 1st week	6.18
6	Feb 2nd week	6.92
7	Feb 3rd week	7.2
8	Feb 4th week	7.88

LEAKAGE OF AIR



The test values can be compared with the design / PG test and historical values. The comparison can also help in detection of measurement errors, if any. The air heater gas side efficiency, air heater leakage, corrected exit gas temperature and measured exit gas temperature, gas side to air side differential pressure and gas side pressure drop can be plotted on a time line graph showing historical, design, and possibly acceptance test data. The leakage with respect to time period is shown in the above figure. It shows that when the time period is changed, then the leakage rate is also increases.

From the observation, we can understand that the leakage is increasing with respect to the change in the time period. The increase in leakage is due to the worn-out of the seal. It is because the regular working condition of the seals in preheater. The pressure difference between the two sides causes the leakage in the flue gas side. The pressure difference is made due to the fan speed.



S.NO	LEAKAGE	CORRECTED TEMPERATURE(˚C)	GAS LEAVING TEMPERATURE AT RAPH (˚C)
1	3.96	216.15	189.99
2	4.78	216.5	183.3
3	5.32	217.02	183.86
4	5.86	218	181.29
5	6.18	220.23	178
6	6.92	223.52	168
7	7.2	226.48	174.02
8	7.88	227.09	168.42

CORRECTED TEMPERATURE

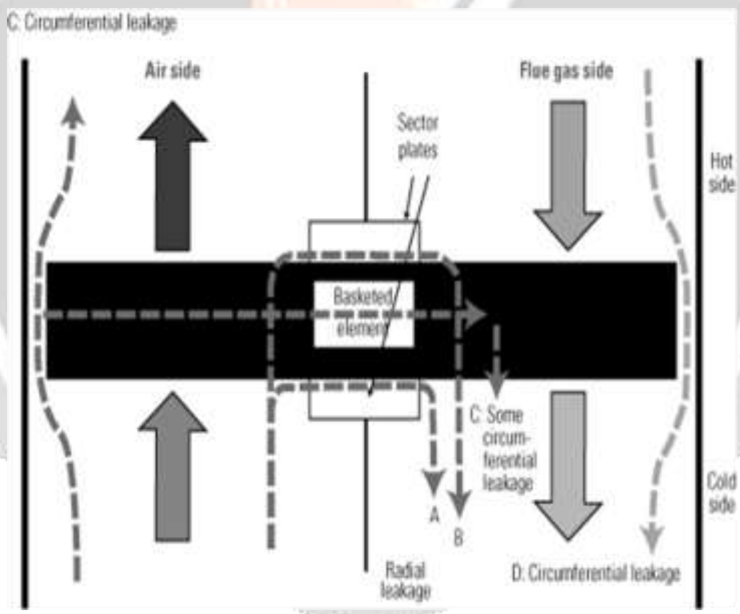
For every % of leakage, there is a drop in the temperature of the exit flue gas. For every 1% leakage, there is a temperature drop of $20^{O}C$ in the flue gas exit temperature. It can be observed in the above table and chart.

4. Observation from leakage of preheater

Regenerative air heaters capture the heat in boiler exhaust gases by passing them over heat-adsorbing metallic elements. The elements are continually rotated so that they alternately contact the heat gases and cool inlet air produced by the plants' forced-draft fans. The captured heat is released into the cooler air and cycled back into the boiler.

It's extremely difficult to seal these types of heaters because their large diameter (up to 600 across) and the large temperature difference between their hot and cold sides (about 400 degree F) together produce dynamic thermal distortion of the rotor. It's not uncommon for the outer edges of a large hot air heater to "drop" (or "turn down") by 2 inches or more, compared with a cold condition.

Figure which is provided shows common leakage paths for typical air heaters. Path A and B illustrate radial leakage between the sector plates and the basket element on the cold and hot sides, respectively.



Radial leakage raises required boiler fan horsepower because it does not contributed to combustion, yet it still must be moved. Paths C and D show circumferential leakage, in which air leaks path the outside of the rotor and thus either fails to be preheated (path C) or fails to transfer its heat to the air heater.

5.Improvements in Leakage Analysis

5.1 Leakage Reduction

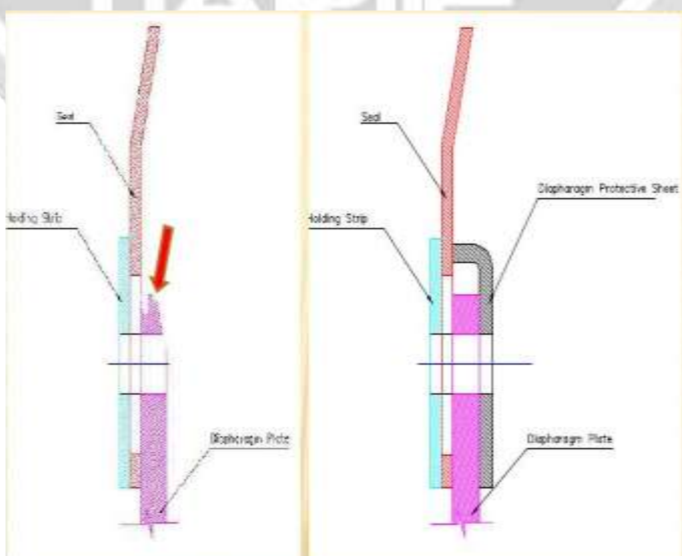
The seal setting done under better supervision should reduce the leakage. Seals are to be set, not only to be fitted.

5.2 Soft Touch Seal

A new concept has been developed to minimize the seal leak. As an introduction, this 'Soft Touch Seal' is provided for hot end radial seal only. This can be extended to axial seal also. Soft touch seal has flexile end that cannot escape air from one basket to another basket. That can be reduces the percentage of air leak to flue gas. Heat transfer is effectively utilized from flue gas to Primary Air and Secondary Air.

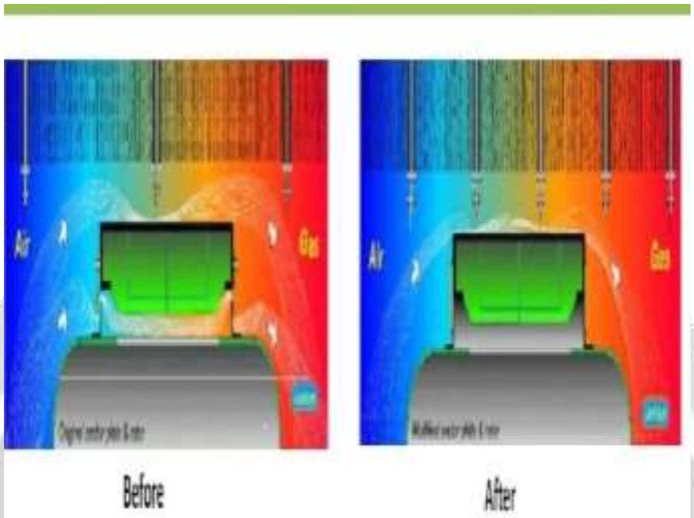
5.3 Plate Protection Sheets

In the conventional air pre-heater, the hot end of the diaphragm plate is exposed to the gas flow. Due to erosive ash particles, the diaphragm plate edges erode fast. In course of time, the erosion extends to the radial seal fixing hole, thereby distributing the fixing and setting of radial seals. The diaphragm plate edge can e protected by the erosive resistant cover plates with the change of seals, these protective sheets also can be changed.



5.4 Double Sealing

In double sealing an additional radial and axial seals are introduced along with the existing seals. This will reduce the overall leakage y 1.5% to 2% recently even triple seals have been introduced. Double Sealing is adapted in the recent design. For old air pre-heaters, this can be retrofitted. This modification will call for the change of all baskets dimensions.



5.5 Steels with enhanced corrosion

The Cor-Ten, ASTM A606-04 standard covers High Strength, Low Alloy (HSLA) steels with enhanced corrosion resistance. The corrosion resistance of these steels is measured and established using the ASTM G 101-04 standard (Standard Guide for Estimating the Corrosion Resistance of Low-Alloy Steels) and a corrosion index is established for each steel that corresponds to the material's resistance to material loss in corrosive environments.

Based on the G101 standard, all ASTM A606-04 steels must have a minimum Corrosion Index (CI) of 6.0 (whereas most carbon steels have a CI of approximately 1.0).

5.6 Composition of corten steel

Tensile Strength = 509.55mpa

Yield Strength = 362.57mpa

MATERIAL	COMPOSITION
Carbon	0.08%
Manganese	0.32%
Silicon	0.34%
Sulphur	0.011%
Phosphorous	0.084%
Chromium	0.50%

Nickel	0.32%
Copper	0.36%

6. Conclusion

The “performance study of regenerative air preheater” was carried out with enthusiasm. During this project a fair knowledge about the working of the total thermal power plant with its high capacity boilers, turbines and other exhaustive auxiliary equipments. The extensive automation of all the equipments at site in the present day world has been studied. In addition, a thorough understanding of the concepts of RAPH has observed.

By this project, the efficiency of the Regenerative Air Pre-Heater was improved by reducing the leakage of air into flue gas in the RAPH, and it is minimized by replacing the ordinary seal into “Soft Seal, Double sealing with Plate protection sheets” and also by proper maintenance of the RAPH.

From this analysis the conclusion is:

- The Thermal performance of the air preheater is improved
- The leakage from air side to gas side is reduced
- Load on the fans are reduced thus power consumption is reduced and cost is reduced
- Fuel consumption is also reduced, thus fuel is saved and cost is reduced

7. References

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