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THE MECHANISM AND APPLICATION OF DeNO_x TECHNOLOGY FOR COAL FIRED UTILITY BOILERS

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ABSTRACT Based on the reaction mechanism of nitrogen and formation of NO_x inside boiler furnace, the development feature and compatibility of several stage combustion technology has been reviewed. At present the key point of DeNO_x is how to select a proper technological approach, which not only cuts down the emission and also upgrades the performance of existing boiler. such approaches, for examples, the gas reburning combustion system in 300MW of Changshu PP developed by Shanghai Jiaotong University, the multi – staged combustion approach in 900mw boiler of Shanghai WGQ PP provided by ALSTOM/EVT and the dense and lean phase combustion method suggested by Laziska Co. Poland are discussed. Besides, a new way for co-firing consideration of Industrial boilers is also briefly recommended. Complying with the environmental protection situation, SPERI as a leading institute in this aspect, has been carrying on plenty of preliminary study in denitration projects, some of which will be realized in coming years.

Keywords: DeNO_x, Stage Combustion, Dense & lean Phase, Gas reburning, Gas/coal Co-firing

1. THE BASIC REVIEW

In China in the visible predicted period of time the power energy consumption mainly relies on coal. The pollution derived from coal combustion takes an obvious portion of the whole emission sources, for example the percentage of sulfur dioxide, nitrogen oxide, carbon dioxide and particulate occupy 87%, 67%, 71% and 60%, respectively. The estimated NO_x emission value being 600~1400mg/Nm³ for oil-fired and 600~1200mg/Nm³ for coal-fired utility boilers in China almost is in double times or more higher than that in developed countries, however since the later years of last century a lot of Chinese utility boilers are equipped with low NO_x combustion system based on the introduced advanced technology, so the NO_x emission could be controlled equally to or lower than 600 mg/Nm³.

According to a fundamental viewpoint the major nitrogen oxides in combustion of coal are NO and NO₂, simplified called NO_x. The quantity of NO_x formation depends on the combustion pattern and its performance, especially the flame temperature and excess combustion air. The formation of NO_x can be defined as the following three typical types, namely thermal NO_x, fuel NO_x and prompt NO_x, while in PC boilers the fuel NO_x dominates and takes more than 60-80% of the total NO_x produced during combustion process

2. DeNO_x MEASURES IN CHINESE UTILITY & INDUSTRIAL BOILERS

Regarding the existing Chinese utility and industrial

boilers most of which were installed in last century and were not forced to cut down the NO_x emission by legislations. However in path with the technique improvement, the control against harmful emission should become more strictly. Even in current publishing atmosphere anti – pollution standard for industrial boilers the maximum NO_x permissive figures are defined for oil and gas fired boilers with the capacity no larger than 65 t/h. There is no permissive NO_x figure specified for coal-fired boilers listed (Tab.1). But actually the new coal-fired utility units which will be put into operation in coming years, are equipped with the update staged combustion technology and for existing utility boilers some applicable measures has been tested for further cutting down the NO_x emission. The coal-fired industrial boilers would have been solely prohibited to be installed or operated in down town area of some modern cities of China, nevertheless, in small and middle cities and where the process gas and NG are available, gas coal co-firing could be a new way to control the NO_x emission effectively. In this paper above mentioned three cases of coal-fired boilers will be described by means of examples.

**Tab.1 The Maximum Permissive Emission by different
Fuels - Fired Boilers (GB 13271 – 2001)**

Fuels Fired	Applicable Area	SO ₂ (mg/m ³)		NO _x (mg/m ³)	
		I	II	I	II
Coal	All area	1200	900	/	/
Diesel	All area	700	500	/	400
Kerosene	All area	1200	900	/	400
Gas	All area	100	100	/	400

I - All boilers operated before 31st Dec. 2000

II - All boilers operated since 1st Jan.2001 (including the boilers which installed in time zone I and retrofitted in time zone II).

3. THE 900MW SUPERCRITICAL BOILER IN WATGAOQIAO PP, SHANGHAI

This boiler designed by ALSTOM (EVT) can be referable to the one of largest bituminous - fired supercritical boilers in the world. According to the actual low NO_x emission (less than 400 mg/m³) requirement in Germany, the boiler combustion system is specially designed, so called "Multi - Staged Method" is applied. Each tangential combustor located in every corner of furnace comprising several cabinets, such as pulverized coal, declination, second and middle air nozzles, among them the declination air nozzles can be horizontally rotated to form a rich air zone against furnace water wall (Fig 1), and all nozzles can be vertically declined to establish expected lean and rich air zone in different combustion stages. Apart from those nozzles a special over fire air nozzle (OFA) located in upper part of furnace is installed

Figure 23. Schematic presentation of air staging at a 110 MW tangential firing [18].

Fig. 1 Multi-staged Coal Firing Technology[1]

The core mechanisms ensuring the effect of denitration in utility boiler, can be summarized as

- (1) The principle of multi-staged combustion is based on sufficient knowledge of coal being burned and some technological criteria has been determined empirically.
- (2) By means of modern measuring and controlling method it could be expected that the composition of flue gas can be detected routinely and meanwhile the result of measurement could be used to adjust the feed rate of air shared in different nozzles of combustor then the staged combustion principle could be fulfilled.
- (3) A stable of coal source should be ensured.
- (4) The inherent uneven distribution of pulverized coal/air flow rate in four corners of furnace should be controlled within a reasonable level.
- (5) For prevent the water wall from high temperature corrosion, a limited boundary zone with rich oxygen content (7%) adjacent furnace inside tubes should be set up.
- (6) The side effect of denitration should be considered and

avoided as far as possible. As well known the staged combustion would cause the unburned carbon losses increase. It can be seen in Fig.2 the produced NO_x controlled by over fire air has inverse relation of loss of incombustible (LOI) measured in a Germany utility boiler.

Fig 2. The inverse relation of NO_x and LOI against different OFA shares

The 900MW supercritical has scheduled to commissioning by the end of 2003, so the actual effect of designed DeNO_x method will be investigated during the operation period..

4. THE APPROACHES FOR RETROFITTING EXISTING OPERATED UTILITY BOILERS

The Reburning Technology has been successfully used as one of for DeNO_x retrofitting technology in Chinese 300MW utility boiler. According to paper [2] a reduced zone is established in furnace to force produced NO to be decomposed at reduced atmosphere, as

Typically the majority fuel (80-85%) will burn at the first combustion zone under stoichiometric coefficient larger than 1 ($\alpha > 1$) and rest part of fuel, usually natural gas, will be enter into upper part of furnace at the temperature range of 1200°C, approximately and under reduced atmosphere, therefore the OFA shall be provided (Fig.3).

Fig. 3 The arrangement of reburning nozzle and OFA[2]

The prospective result of retrofitting in 300MW of Wangting PP is described in paper [2] that the emitted NO_x is 60-70% of the original value measured. However the success of such modification highly depends on one hand of excellently organized retrofitting engineering and the proven hardware applied as well as on other hand of expertise operation staff.

The another approach has been investigated by SPERI in corporation with Polish Laziska Co. in 2002. One 100MW old coal-fired boiler had been taken as the example for preliminary feasibility study. The key technology used can be defined as "Dense & Lean Phases Combustion of Coal Dust in Furnace" as shown in Fig.4

Fig.4 The model of DeNO_x technology of Lasiska Co.

This approach features also to use modified classifier of pulverizer or PC feeder system and the connecting piping from mills to different rows of burners mounted in boiler furnace so three stage combustion can be realized. That means in the lower part of furnace the dense phased and coarse coal particulate burns under substoichiometric atmosphere, in the middle part the lean phased and finer coal particulate burns under almost normal condition and all particulate will burn out under the OFA upper zone of furnace.

In theoretical viewpoint when the volatile content of coal ignited and burns it needed oxygen supplied, therefore the more of oxygen needed for volatile burning the less amount of which can be used for formation of NO_x[4]. Here the specified term of oxygen ratio ω is derived, which is equal to the ratio of amount of oxygen in the pyrolysis

zone at the burner outlet and oxygen demanded for volatile combustion.

$$\omega = \frac{0.21 \frac{100 - W_t^r}{100 - W_p} \frac{1}{\mu_{\mu p n}} + \frac{0.01 O^r}{\rho_{O_2}}}{0.0021 V^r V_p^r (V)} \quad (5)$$

where

μ_{pn} – coal concentration conversed to normal condition, kg.f/Nm³.

O^r – oxygen content in fuel (combustible basis), %.

ρ_{O_2} – oxygen density under normal condition, kg/Nm³.

$V_p^r (V)$ – oxygen needed for volatile combustion / kg.,

V^r – volatile content (as burned), %.

W_t^r – total humidity %,.

W_p – humidity in coal dust %.

Based on the calculated ω the proper share of air in the first stage of combustion can be determined.

The main steps and important procedure of retrofitting by this method can be listed as follows:

- (1) Combustion air amount shall be strictly controlled according to the given measure and the excess air should be in the range of 1.18- 1.20.
- (2) To change the coal feeding mode as the most (70-80%) dense phased and coarse coal dust fed into burners at lower furnace, and the less fine lean phased coal dust fed into burner at upper furnace and almost 5% of combustion air enters the furnace through OFA nozzles.
- (3) To control stringently and continuously the temperature and CO content of flue gas in boiler right and left two gas ducts, the measured data can be used for feedback signals for monitoring the combustion process and eliminating the LOI as far as possible.

The merit of this approach compared to others is come up with the following facts:

- (1) To movement track of coal particulate, especially large sized coarse coal dust is prolonged when passing through the furnace. It's beneficial for completely burn out of coal. Both environmental friendly and energy saving purpose would be obtained, if a proper design and precise engineering could be organized. It is recorded the NO_x can reduce to 470mg/m³ while the boiler efficiency can be improved by 1-2%.
- (2) The reduced atmosphere zone exists only in lower part of furnace where the gas temperature is lower, too. So the damage of high temperature corrosion was not discovered in some utility boilers retrofitted by this approach in Poland.

However the more complicate engineering including to change the layout of coal dust piping, usually makes hesitation on the acceptance of this approach in some

utilities.

Nevertheless SPERI will make attempt seeking a candidate for retrofitting in international cooperation mode.

5. GAS COAL CO-FIRING TECHNOLOGY IN BRIEF

This method is similar to Reburning technology but utilized in small and middle sized industrial stoker or grating firing boilers[4]. The combustion mechanisms reveals that a gas flame over the coal grate will create "Three T Effects" namely high Temperature, high Turbulence and prolonged residual Time of coal dust in furnace.

Fig. 5 The characteristics of coal burning over the grate

In Fig.5 the coal (char) burn out procedure is illustrated, where the $O_2O_3O_4$ represents the front of char flame and O_5O_6 represents the completely burn out of char. When the gas flame added in the furnace the O_5O_6 moves left and predicts the burn out could be fast. The β covered zone ($\beta = \beta_{max}$) in the chart is volatile matter emitting area and is also rich of fine particulate, which under gas supplemental flame can be rapidly burn out and consequently, the efficiency of combustion will increase accordingly.

For denitration purpose it usually to introduce part of combustion air through grate and other part through the gas burners air nozzle, so the two staged combustion will be set up.

SPERI starts cooperate with CALPENN ASSOCIATES, INC. of US for carrying on the retrofitting of coal - fired industrial boiler on so called SGMB system utilizing multi individual gas nozzle mounted in the furnace penetrating into the gaps between water wall tubes. The scattered flame simulates the coal firing on grate and without the overheated hottest point on heating surface, which would jeopardize the expected purpose.

The NO_x emission can be less than 30% of the original value, the American experience has proved.

Fig.6 The SGMB system

SPERI has developed a new kind of "Coordinate Control Panel" for boiler converted into co-firing which links the BMS of SGMB and existing boiler load following up controller to fulfill the different operating modes such as "gas firing preferable", "coal firing preferable" or "environmental protection preferable". When the boiler load demand changes.

The demonstration project of co-firing industrial boiler will be expected establishing in Shanghai later this year.

6. CONCLUSION

DeNO_x technology becomes definitely a hot point in power engineering practice in China soon, even though according to existing Chinese Environmental Protection Code the NO_x emission is not stringently stipulated. This technology will be developed under the influence of local economical situation and the pressure claimed by local environmental protection authorities. However the proper way should be chosen case by case. The conception of this paper covers the potential approaches suitable for DeNO_x of new installed and existing utility boilers, even the interesting way of co-firing for industrial boilers are also discussed briefly. It is believable that to improvement of atmosphere quality is the task of all people who are involved in aspect of power engineering.

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