NATURAL GAS REBURN FOR EMISSIONS REDUCTION FROM COAL-FIRED POWER PLANT

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1. INTRODUCTION

From 1980 to the present day world energy use has increased by 50%. Growth in power generation approaches 100% over the same time-scale [1, 2]. With the current increasing world-wide energy demand and with the fossil fuel reserves predicted, it is anticipated that global electricity production from coal and natural gas will increase. Indeed in both the Western, developed economies and in the rapidly expanding energy infrastructures in Asia, it is expected that coal will continue to be used for power generation for many years. At the present time coal supplies around 30% of world-wide total energy demand (about 50% of which is being used in power generation). This percentage distribution will probably remain constant especially with regard to the substantial coal reserves yet to be exploited in China and many other countries.

Power generation accounts for significant emissions of carbon dioxide and other pollutants such as sulphur oxides, nitrogen oxides and particulates. Whilst Kyoto and the IPCC have focused on greenhouse gas emissions, other legislation is required to deal with the other pollutant species. In Europe this is through the Large Combustion Plant Directive (LCPD) [3] and National Emissions Ceiling Directive (NEC) [4]. It is clear that improved environmental performance from coal-fired power generation is required to reduce gaseous pollutants and carbon dioxide emissions. Some of the emissions reduction can be realised though improvements to power plant generation efficiency and newer boiler types, like supercritical, will assist in reducing emissions. One technological development for the cleaner operation of coal-fired plant is to opt for hybrid use of natural gas and coal [5]. This not only improves fuel flexibility but also improves the emissions performance of the boiler. So there is opportunity to establish emissions reduction from existing boiler plant through the retrofit of technologies like natural gas reburn. These retrofit options are at significantly lower cost than any new-build plant and are beneficial to plant operators in that it can assist with continued use of an existing capital asset.

Natural gas reburn technology has been demonstrated successfully around the world at a range of scales. It is a cost-effective method of emissions reduction and recently it has been suggested that natural gas reburn technology has become established as a proven NOx reduction technology [6] but with recent advances and developments the basic technology is being extended and adapted to further improve its NOx reduction capability and overall performance. This paper reviews the current status of natural gas reburn technologies available.

2. BACKGROUND TO NATURAL GAS REBURN TECHNOLOGY

Reburn technology, is a technique primarily developed for the reduction of NOx [7]. It is a staged fuel approach using the entire volume of a furnace rather than control of the NOx production and destruction within the envelope from the flame. Reburn is a three-stage combustion process with the three stages commonly referred to as primary, reburn and burnout zones. The application of natural gas reburn to a front-wall fired boiler is shown schematically in Figure 1.

In the primary zone, pulverized coal is fired through conventional or low-NOx burners operating at low excess air. In this zone it is important to obtain the complete combustion of the coal and thus produce NOx from the fuel-nitrogen, and, prompt and thermal NOx. A second fuel injection is made in a region of the boiler after the coal combustion creating a fuel rich reaction zone (the reburn or reburning zone). Here reactive radical species are produced from the natural gas and these chemically react with the NOx produced in the primary zone to reduce it to molecular nitrogen. The partial combustion of the natural gas in this reburn zone results in high levels of carbon monoxide and a final addition of overfire air, creating the burnout zone, completes the overall combustion process.

The range of fuels that have been used for reburn is wide. Coal [8], oil [9], orimulsion [10], gasified biomass [11], coal water slurry, and natural gas have all been used as reburn fuels and all give NOx reduction. Of these the easiest to engineer and use is natural gas. Typically natural gas gives the greatest NOx reduction performance as a result of the fact that it easy to inject and control, and that it does not contain any fuel-nitrogen. Natural gas reburn can give up to 70% reduction in NOx emission and there are additional environmental benefits from using gas as the reburn fuel, as a consequence of its clean combustion characteristics. Emissions of SO_2, particulate and carbon dioxide are also reduced.

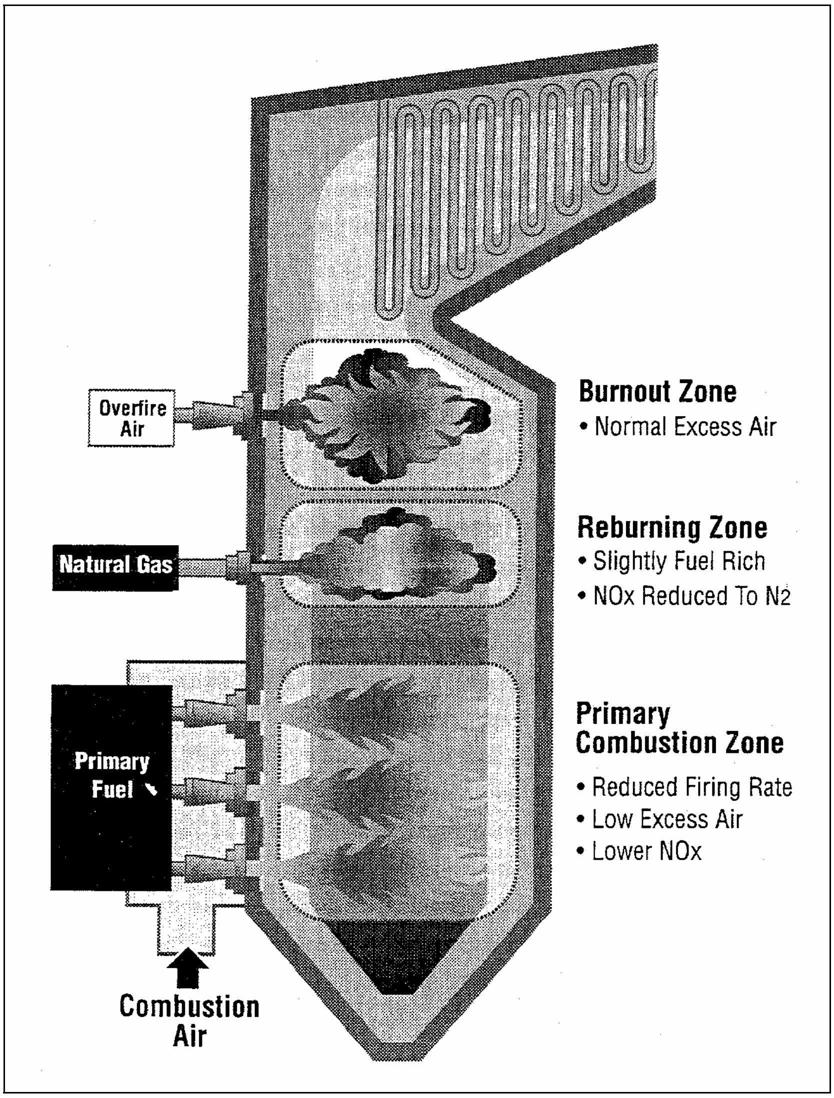

Figure 1: Schematic diagram of natural gas reburn applied to a front-wall fired boiler.

Basic natural gas reburn technology relies on several factors to ensure good operation of the boiler and efficient NOx reduction. Most gas reburn systems on large boilers use recirculated flue gas to improve the injection of natural gas and mixing of the gas within the boiler. Although this involves both a cost and electrical generation efficiency penalty, it has been shown to be important for the larger natural gas reburn installations. The NOx reduction capability of the overall gas reburn process is dependent on several factors including:

- reburn zone residence time
- reburn zone temperature
- mixing of the natural gas within the boiler with the combustion products from the coal combustion in the primary zone
- overfire air mixing
- residence time in the burnout zone

To fully understand the impact of these factors it is necessary to understand the bulk flow within the boiler and the physical constraints around the boiler for introduction of gas and air injectors. Figure 2 shows the layout of a front-wall fired boiler together with the additional equipment required for a standard natural gas reburn system.

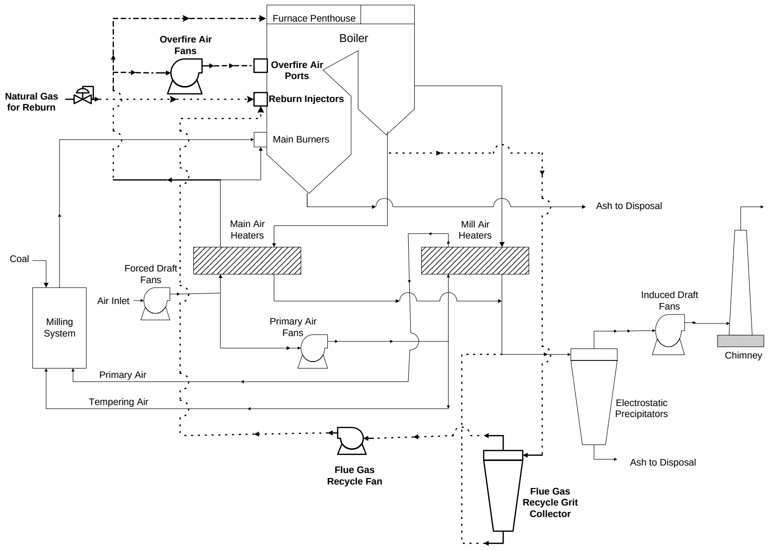

Figure 2: Schematic layout of a typical gas reburn system
(dashed lines show additional process flows for the reburn system over that for the basic plant)

3. NATURAL GAS REBURN DEMONSTRATION PROJECTS

There have been several reburn demonstration projects in the USA and Europe and many have used natural gas as the reburn fuel to explore the different NOx reduction potential with change in boiler type and size. The largest demonstration of reburn in the world up to the present time is the gas reburn installation on a 600MWe boiler at ScottishPower's Longannet power station. Table 1 lists some of the natural gas demonstration projects completed at the present time. The range of boiler types and sizes shows that natural gas reburn can be readily applied to most boilers. Recent plans to install gas reburn on opposed wall-fired boilers are being developed by GE-EER [12].

Site	Size (MWe)	Firing System	Reburn Heat Input (%)	NO_x Reduction (%)
Illinois Power Hennepin #1, USA	71	T	10 -18	67
Springfield CWLP Lakeside #2, USA	33	Cy	23	60
Public Services Colorado Cherokee #3, USA	156	W	20	72
Ohio Edison Niles #5, USA	100	Cy	16	45
Kansas Power & Light Lawrence #5, USA	300	T	10	50
Stadtwerke Wuppertal Germany	125	W	10	50
Malmo Energi Limhamn, Sweden	125	T	16	50
Ladizhyn, Ukraine	300	W	12-20	50
ScottishPower Longannet #2, Scotland	600	W	20	50

Table 1: Natural gas reburn demonstration projects and NOx reduction
(For Firing System: T = Tangential, Cy = Cyclone and W = Wall)

4. ENHANCEMENTS TO GAS REBURN TECHNOLOGY

The first demonstration projects started around 1990 and the benefits were readily established in terms of ease of operation and NOx reduction. There is substantial on-going development work on reburn including reburn injector designs and optimisation of the overall system to maximise emissions reduction performance whilst maintaining plant integrity and efficiency. A key aspect of this development is to reduce the requirement for recirculated flue gas. This has benefits both to the capital cost of the retrofit technology and is O&M costs also.

The basic natural gas reburn technology has been extended and there are now several variants and complementary technologies all based on natural gas reburn but adding additional functionality for specific applications. These include:

- advanced gas reburn
  This was one of the first extensions of basic gas reburn technology. Here a combination of reburn and selective non-catalytic reduction (SNCR) is used to give some improvement to the NOx reduction capability. Figure 3 shows a schematic diagram of the technology applied to a wall-fired boiler. In advanced gas reburn, the SNCR (nitrogen) agent is injected into the boiler above the burnout zone. It relies on thermal de-NOx chemistry constraining the technology as the operating temperature window for de-NOx is relatively small. Thus the injection of the SNCR agent has to be carefully controlled. However, there are benefits in using this hybrid approach rather than stand-alone SNCR [12].
- gas reburn with sorbent injection (GR-SI)
  This coupled technology combines the reduction of SO_2 emissions through use of a sorbent alongside the NOx reduction by gas reburn, The reburn gas injection is the same as that for a standard gas reburn system but the sorbent injection is made alongside the overfire air [13]. 60% NOx reduction has been demonstrated and about 50% reduction in SO_2 emissions when firing medium-sulphur-content coals.
- Close-coupled gas reburn (CC-GR)
  This is a similar technology to Close-coupled Overfire air (CC-OFA) and is specifically applied to tangentially-fired boilers. The technology has been developed by Andover Technology Partners and involves injection of gas through an existing port in the burner bank. The reburn and primary zones are not distinct and the potential NOx reduction is not as great as a conventional gas reburn system. However, there are benefits in terms of reduced capital cost.
- Fuel lean gas reburn (FLGR^{TM}) [14]
  FLGR^{TM} was invented by Energy Systems Associates and developed by the Gas Research Institute. For this technology gas input levels are lower than a traditional gas reburn system and involve gas injection (using multiple high-velocity turbulent gas jets) into the upper furnace volume of a utility boiler avoiding the generation of a fuel-rich reburn zone. In this way the need for burnout air addition is removed and the capital cost of the installations is reduced. However, NOx reduction performance is not as good as a standard gas reburn system. 30-45% NOx reduction is possible with gas heat input to the boiler of between 5 and 7%.
- Amine enhanced fuel lean gas reburn (AEFLGR ^{TM})
  This is a combination of the FLGR system with urea-based SNCR and is currently being demonstrated in the USA. AEFLGR ^{TM} jointly utilises natural gas (at up to 10% of the total boiler heat input) and an amine-containing compound (for example urea) to achieve potential NOx reductions of 70%. As this technology avoids recirculated flue gas and overfire air injection it is significantly lower cost than traditional gas reburn. However, injection of amine-containing compounds may results in increased corrosion and materials issues may add to O&M costs.
- Methane de-NOx ^{TM}
  This technology is the gas reburn equivalent technology designed for stoker-fired boilers. The technology was first developed by the Gas Technology Institute and is now supported by and licensed to Energy Systems Associates. It involves gas injection together with recirculated flue gas in a region of the boiler above the grate after the NOx has been formed from the combustion on the grate. Methane de-NOx ^{TM} can give NOx emissions reductions of up to 70% and can increase overall boiler thermal efficiency.
- Selective autocatalytic reduction (SACR)
  this is similar to advanced gas reburn except that the methane and ammonia (NH_3) are injected simultaneously. Large test rig trials have shown NOx reductions up to 80% and a full-scale demonstration is planned in the USA.

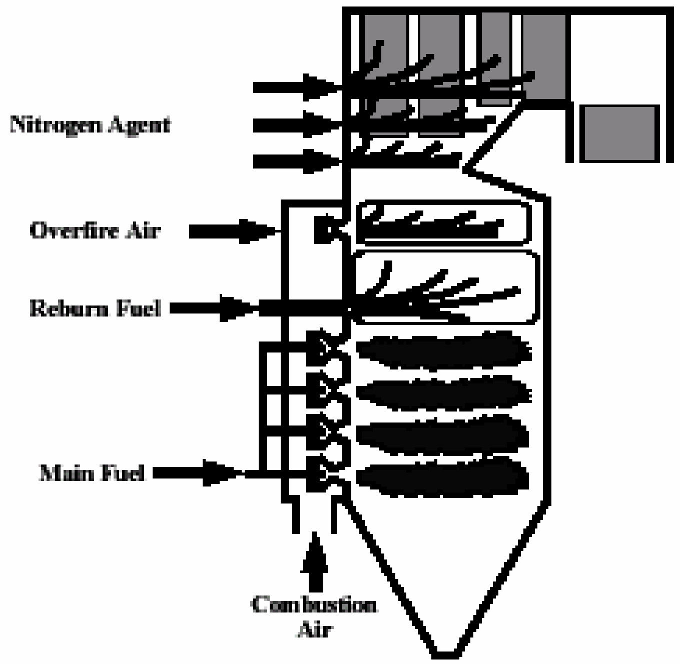

Figure 3: Schematic diagram of advanced gas reburn applied to a front-wall fired boiler [12].

4.1. Related technology to natural gas reburn

As well as reburn for NOx reduction, natural gas can be used in other technologies to improve the emissions performance of coal-fired power plant. Details of two of these technologies are:

- Gas cofiring
  Here, natural gas and pulverized coal are fired in the same burner arrangement, or potentially in dedicated burner rows or warm-up lances. Tests in the USA have shown that up to 50% gas heat input can be used with reductions in NOx, SO_2 and particulates. Capital and operating costs of co-firing systems are typically lower than reburn systems though the NOx reduction capability is lower.
- Pulverized Coal Preheat Burner
  The Gas Technology Institute is developing the Pulverized Coal Preheat Burner in collaboration with the All-Russian Thermal Engineering Institute (VTI). This preheat burner, fired by natural gas, preheats the pulverized coal to release the volatile components of coal into a fuel-rich, reducing environment that converts the fuel-nitrogen to molecular nitrogen in a similar way to standard reburn chemistry. The resultant fuel stream of char, hydrogen, low molecular weight hydrocarbons and carbon monoxide are fired through modified burners into the standard boiler.

5. ENVIRONMENTAL BENEFITS AND ECONOMICS OF NATURAL GAS REBURN TECHNOLOGY

The environmental benefits of reburn technology based on natural gas applied to coal-fired power plant are well established and the techno-economic assessments show that the technology is competitive with other NOx control systems with the added benefit of reduced carbon dioxide emission as well. Capital costs are reasonable compared to SNCR and SCR technology and operating costs are dominated by fuel costs. If gas costs are similar to the primary fuel then the cost of electricity generation in a gas reburn system is lower than for 100% coal firing.

Figure 4 shows how electricity generation costs vary with coal price, for a range of gas prices, when utilising gas reburn technology. It shows that when gas costs are low, then significant cost savings can be made by implementing gas reburn technology. As the price of gas increases, then for reburn to be competitive the coal prices must be at a premium too. Even so, it should be realised that competitive fuel cost is not uppermost in the minds of the utilities, and that they are prepared to pay for the positive environmental impact that gas technologies bring.

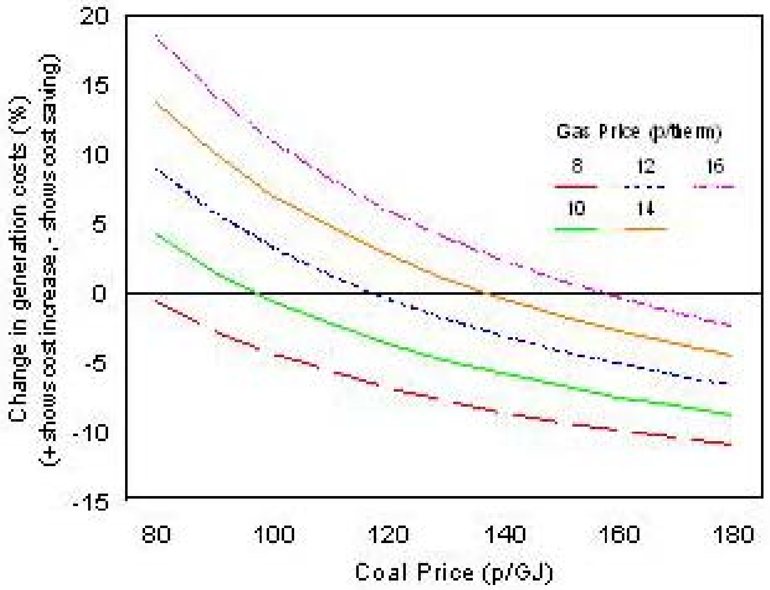

Figure 4: Effect of fuel price on the cost of electricity generation using 20% gas reburn technology

Figure 5 illustrates how the generating costs change with load factor. It is clear that the best benefits are obtained for a unit that is operated at high load factor. As the unit load factor is increased, the generating costs due to gas reburn technology decreases. For example, at 20% loading, generating costs increase by 0.22% on the baseline case. When the load factor is increased to 80%, then savings of 0.53% occur. Another way to compare the data is to look at what happens when a change in load factor occurs. If a plant is running at 65% load factor, and this value reduces by 5%, then the electrical generating costs will vary from 0.47% saving to 0.44%, an increase of 0.03%. However, if the plant is running at only 25% load factor and again reduces by 5% then the resulting generating costs will alter from 0.02% additional cost to 0.22%, an increase of 0.20%.

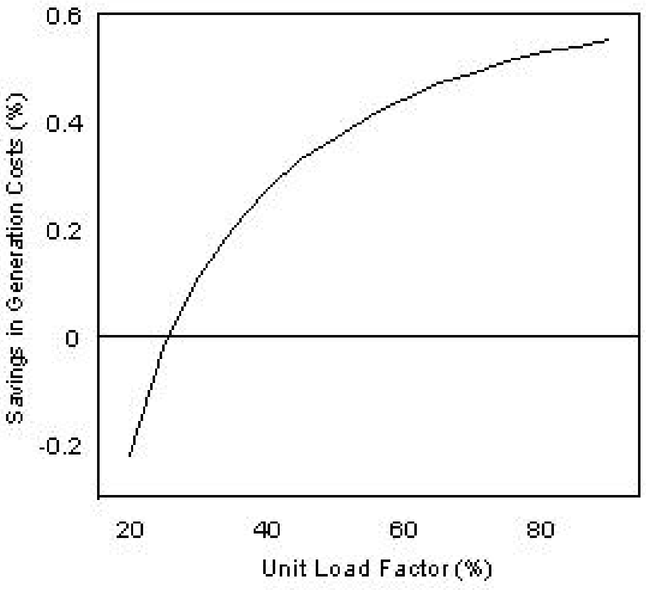

Figure 5: Effect of Unit Load Factor on Electricity Generating Costs at 20% Gas Reburn

6. CONCLUSIONS

Natural gas reburn technology has been demonstrated on a range of boiler types and with different firing arrangements. It is clear that the standard, basic reburn technology has been developed to such an extent that it can be described as a fully proven technology. Developments are underway to improve the NOx reduction performance of reburn-like systems by combining traditional reburn approaches with other technologies in a hybrid approach. Whilst these extensions to the technology are not fully proven at the moment, it is expected that many will become viable, economic options for coal-fired plant to consider for emissions reduction retrofit.

Natural gas reburn technology is economically competitive with standard SNCR systems and significantly lower cost than SCR applications. The future prospects for industries capable of retrofitting gas reburn and related technology looks encouraging, as concerns over greenhouse gas emissions increases and emissions legislation becomes more stringent.

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