FLUE GAS RECIRCULATION

FOR

STOKER BOILERS

Calpenn Associates, Inc.
(A Kenneth L. Maloney, PhD, Inc. Company)

www.combustionexperts.com

FLUE GAS RECIRCULATION SYSTEMS FOR STOKER BOILERS

Flue Gas Recirculation (FGR) is a patented combustion modification process for stoker-fired boilers that will increase boiler efficiency and steaming capacity, while at the same time reduce particulates, stack opacity and NOx emissions. Emissions of sulfur oxides (SOx) can also be controlled with FGR when limestone is added to the fuel in the form of a coal/limestone pellet.

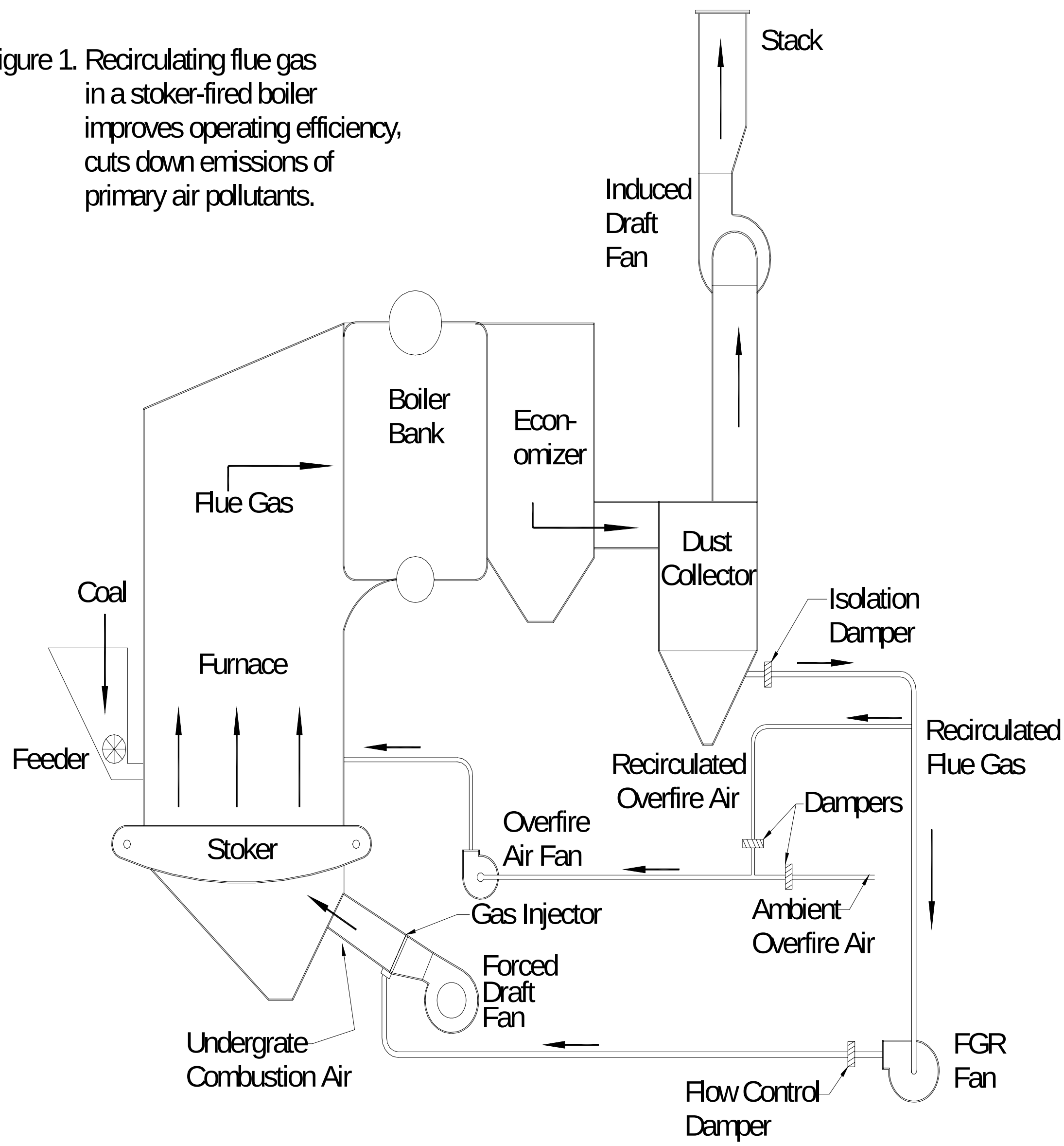
A SYSTEM THAT PAYS FOR ITSELF

Operators of stoker boilers, particularly those installed several years ago, must contend with the changing environmental regulations and increasing fuel costs, in addition to the usual operating problems. The Calpenn Associates, Inc. (a sister company to Kenneth L. Maloney, PhD, Inc.) Flue Gas Recirculation system provides a unique solution that will solve emission and operational problems while paying for itself with improved boiler efficiency. Simple payback periods of 1-2 years are common for many of our installations. The FGR system can be retrofitted to all types and sizes of stoker-fired boilers including spreader stokers with traveling grates, vibrating grates and dump grates as well as traveling chain grates and underfeed stokers with single, double and multiple retorts. The FGR process is applicable to all fuels that are fired on a grate including coal, wood, biomass, tires, e-fuel and garbage.

THE CONCEPT

Flue gas is diverted from a location downstream of the main boiler bank and is mixed with the combustion air from the forced draft fan. In some cases the flue gas might also be mixed in with the overfire air. The recirculated flue gas takes the place of greater amounts of excess air that the stoker would normally use to keep the burning fuel bed cool to avoid clinkering and grate overheating. The FGR system allows the cooling and the combustion requirements of the forced draft air to be “de-coupled”. The cooling effect comes from the moisture and CO_2 contained in the flue gas. The flue gas has a greater heat capacity than air so it carries more heat away from the fuel bed and reduces peak temperatures by as much as 250° F. With the use of the FGR system, fuel bed cooling can now be accomplished independent of air requirements for the combustion of the fuel. The FGR system allows the stoker boiler to operate at very low excess air levels. Fifteen to twenty percent excess air operation is easily achieved with the FGR system. This reduction in excess air reduces the velocity of the flue gas in the boiler and therefore reduces the amount of flyash that is entrained in the gas stream exiting the boiler.

Figure 1. Recirculating flue gas in a stoker-fired boiler improves operating efficiency, cuts down emissions of primary air pollutants.



HOPPER EVACUATION OF THE MECHANICAL DUST COLLECTOR

When the flue gas is taken from the hopper section of the multiclone mechanical dust collector, the pressure drop across the collecting cyclone tubes is increased at all gas flow volumes. This increase in pressure drop increases the "spin" velocity in the tubes and the centrifugal forces on the flyash particulate which results in an increase in dust collection efficiency. The dust collector also collects more of the smaller particles; those under 10 microns which normally escape from the unit. The combination of lower flue gas flow and improved dust collector efficiency result in boiler emission rates on the order of 0.05 pounds per million Btu's.

PROVEN TECHNOLOGY

Calpenn Associates, Inc. has installed over 50 FGR systems in this country on all types and sizes of stoker fired boilers. The first commercial application of FGR to a stoker boiler in the United States became operational in 1981. Four units at this location have been operating since they were installed. The Calpenn Flue Gas Recirculation system is recognized as acceptable and proven control technology for stoker fired units in Michigan, Pennsylvania, Ohio, Virginia, West Virginia, Wisconsin, Washington, North Carolina, Illinois, Indiana and Oregon. In addition to reductions in particulate and opacity along with fuel efficiency gains, the FGR system can also lower fly ash and bottom ash carbon content as well as reduce NOx and SOx emissions. The stoker owner can buy a cheaper grade of fuel, since the FGR equipped unit will tolerate more fines in the fuel as well as a lower ash fusion point.

THE HARDWARE

The FGR system consists of a series of ducts that connect the flue gas take-off point with the flue gas recirculation fan along with ducts that connect the FGR fan with the gas injection point downstream of the forced draft fan. Isolation and control dampers are placed in the ducting to control the flue gas flow and to isolate the system when not in use. At any time the FGR system can be isolated and shut down and the boiler will continue to operate in its pre-FGR mode. All flues and ducts are made of heavy gauge steel. The elbows and damper blades are fabricated from abrasion resistant (AR) material. The FGR fan is an armored radial blade fan with scroll liners and blades of AR material. The fan specifications include a low rotation speed to reduce wear and increase life. A secondary mechanical dust collector can also be installed to extract the majority of the flyash from the FGR system before passing through the ducting, dampers and fan. The FGR flow control damper is equipped with an actuating unit that receives a signal from a controller (PLC or DCS based) located in the control room. The flow control damper can be operated in either automatic or manual mode. In the automatic mode the FGR system uses a temperature base control scheme. The temperatures required for automatic operation are ambient air, flue gas temperature at the FGR fan and the temperature of the mixture of flue gas and air. With these temperatures the %FGR can be calculated and a curve can be programmed to maintain a boiler load versus %FGR curve. If the FGR system were taken out of service the boiler controls would revert back to the pre-FGR operating conditions and follow the old air versus load curve.

OVERFIRE AIR

In some cases modifications are made to the overfire air system to improve the mixing in the furnace to reduce soot formation and the resulting opacity that it causes. These modifications are aimed at increasing the penetration of the overfire air to reach those portions of the over bed regions that are not well mixed. FGR can be added to the overfire air in certain applications to aid in the mixing objective and to further reduce the excess air in the furnace.

If the boiler is deemed to have inadequate overfire air, modifications to the overfire air system will be included in the FGR system installation. New overfire air jets may be required and existing jets may need to be enlarged. When this is the case the manifolding and the overfire air fan capacities will need to be increased. On larger units there might be the requirement to put flue gas into the overfire air to reduce the amount of fresh air that is entering the furnace above the fuel bed. When FGR is used in the overfire air it acts to dilute the air while maintaining the mass flow and the penetration of the jet to provide the required mixing in the furnace.

FAIL SAFE

The flow control damper is interlocked with the FGR fan so that the damper cannot be opened until the FGR fan motor is energized and will automatically close if the fan fails. The flow logic of the system is such that even if the FGR dampers were open when the FGR fan shuts down, the only thing that would happen is that fresh air would pass through the FGR system into the dust collector and out the stack. There is always plenty of time to close the isolation dampers and prevent the flow of air through the FGR system. The FGR system can be shut down at any time and the boiler returned to its pre-FGR operational configuration. The FGR system will not limit steam generation in any way or cause a forced outage at any time.

GUARANTEED RESULTS

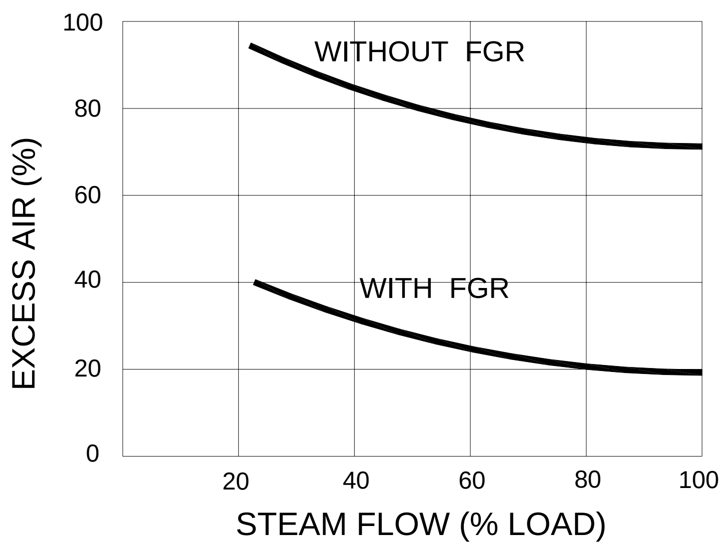
Calpenn Associates, Inc. has sufficient experience with the FGR system to be in a position to offer performance guarantees in most applications. Calpenn has been successful in meeting the guarantees offered to clients. We have a current list of FGR users that can be contacted or visited who will discuss their FGR operating histories with prospective clients.

THE BENEFITS

INCREASES BOILER EFFICIENCY

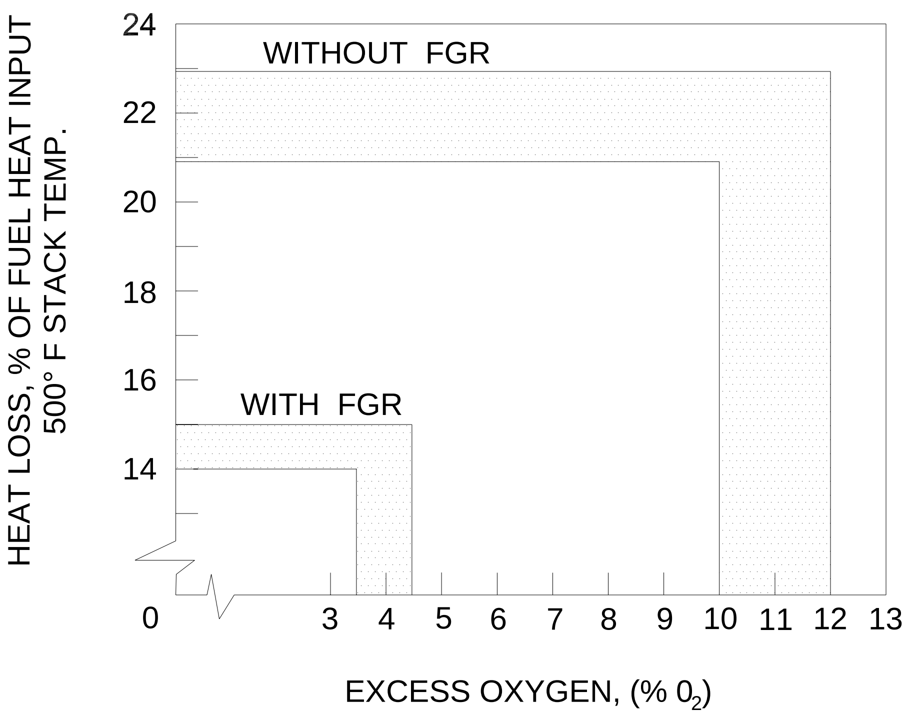
LOWERS EXCESS AIR

A 50% or greater reduction in the excess air required for stable operation and for inhibiting the fusion of ash into clinkers. Lower excess air translates directly into fuel savings and reduced NOx formation.



FUEL SAVINGS

Fuel savings of 7% or more result because reducing excess air means a reduction in the flue gas out the stack and a savings in the fuel that would otherwise be needed to heat that excess air.

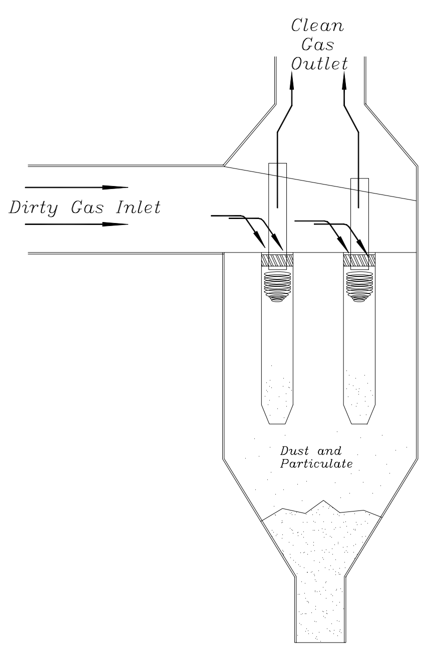


REDUCED PARTICULATE AND OPACITY

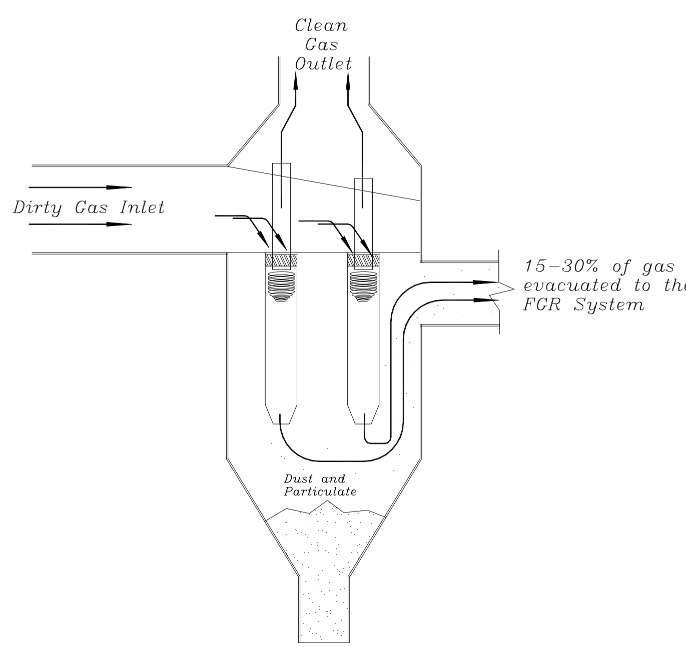
A major benefit of the FGR system is the reduction in stack particulate loading and opacity. When flue gas is extracted downstream of the I.D. fan, particulate reductions are in the range of 40-50%. When the gas is extracted from the hopper of a mechanical dust collector, particulate reductions as high as 70-75% are possible.

HOPPER EVACUATION / FGR

Removing a portion of the gas from the hopper of a mechanical dust collector reduces the re-entrainment of fine particulate inside the dust collector and improves overall multi-clone performance. Traditionally, the extracted flue gas was passed through a secondary baghouse. However, flue gas extracted from the hopper of a mechanical dust collector and recirculated through the boiler is a proven alternative to the use of a secondary baghouse. A flue gas recirculation/hopper evacuation system will cost less than one half the cost of a conventional hopper evacuation/baghouse system. In addition, the flue gas recirculation system will pay for itself usually in less than two years.



Normal Operation



Hopper Evacuation/FGR

REDUCED NOx EMISSIONS

Flue Gas Recirculation is recognized by the US EPA and the State EPA's as an acceptable control technology for NOx emissions. This work was used to set the NOx reduction goals for new stoker boilers. The graph below contains NOx data from coal fired stoker boilers. As you can see, NOx emissions are higher at higher excess air. The data point with the lowest NOx measurement is from a boiler using Flue Gas Recirculation.

NOx arises from two sources in combustion systems:

1) Fixation of atmospheric nitrogen in the air

   $O + N_2 = NO + N$
   $N + O_2 = NO + O$

   This process occurs more rapidly at higher temperatures and higher oxygen concentrations.

2) Conversion of fuel bound nitrogen to NOx.

   Fuel $NH_2 + O_2 = NO + H_2O$
   Fuel $CN + O_2 = NO + CO$

   This process also occurs more rapidly at higher temperatures and higher oxygen concentrations. So reducing the combustion process peak temperatures and lowering the oxygen concentration will slow down NOx formation.

The ability to operate at lower excess air is the primary variable that affects NOx reduction. However, there are other factors that act to reduce NOx. The flue gas cools the fuel bed without the increase in excess air and thereby lowers the conversion of fuel bound nitrogen to NOx.

AIR STAGING FOR LOWER NOx

Stoker boilers have the benefit of being in the natural "staged air" configuration with the overfire air system supplying the "staged air" above the fuel bed. Research has shown that if the stoichiometry of the first stage (the coal bed) can be controlled to the 2-3% excess oxygen level then a reduction in NOx occurs when the staged air is added above the fuel bed. This staging configuration accomplishes both a reduction in temperature of the first stage and a delayed mixing of the final combustion air to the time when the flame is not as hot.

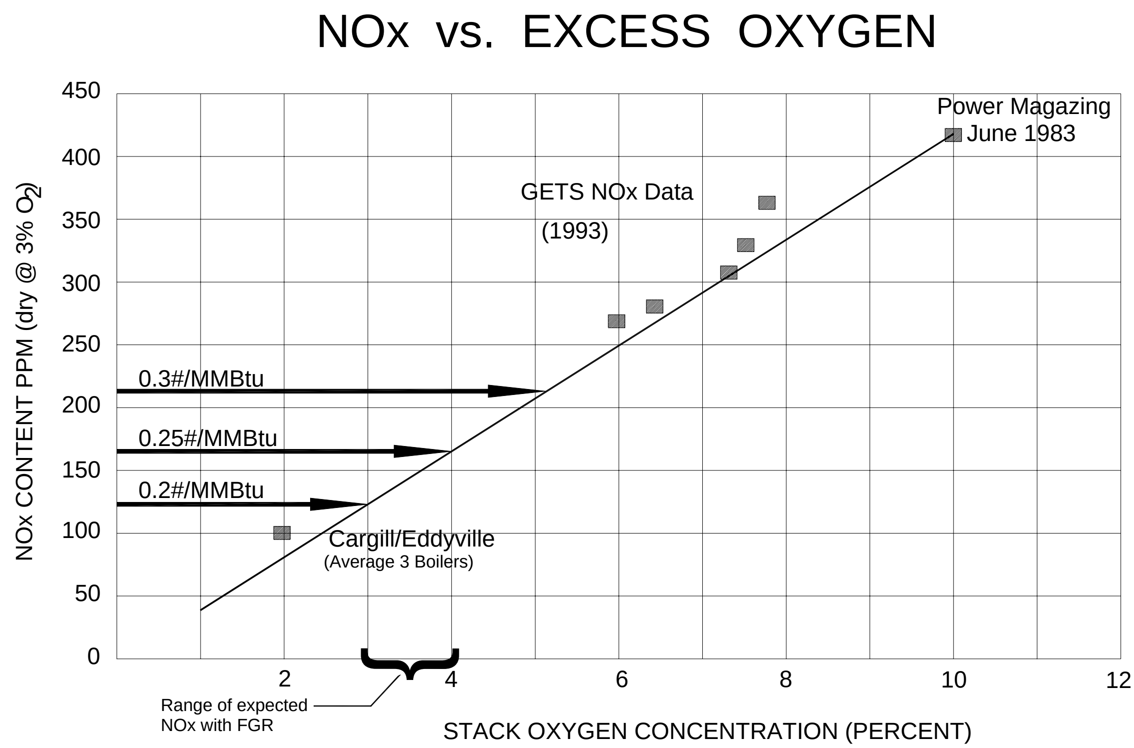
There is also some important chemistry that is triggered when flames are staged in this manner. The chemistry is akin to the injection of ammonia for the reduction of NOx in flue gases. However, in the case of the flame, the ammonia is formed in the fuel rich flame (1^{st} stage) and its reaction with the formed NOx is triggered by the addition of air in the second stage. All of this gives rise to a low NOx combustion system. In a stoker you have a naturally "staged" configuration but no good way to control the first stage stoichiometry. This is where Flue Gas Recirculation comes in. It allows control over the first stage stoichiometry down to the levels that trigger the staged firing NOx reductions. This is why the FGR NOx curve falls below the baseline NOx curve.

So, to recap, the NOx reduction mechanisms of FGR are:

1) Lower excess air firing (Thermal NOx reduction).

2) Cooler fuel bed operation (Lower fuel bound nitrogen conversion to NOx).

3) Staged combustion operation with control over the first stage stoichiometry (Lower thermal and fuel bound NOx).



Lower excess air requirements and overfire air modifications can result in NOx emissions down to 0.2 #/MMBtu on sub-bituminous coal and 0.3#/MMBtu on bituminous coal.

INCREASED STEAMING CAPACITY

A 10-20% increase in steaming capacity can be achieved if the boiler is limited by fan capacity, stack opacity, particulate emissions or furnace pressure.

COMBUSTION IMPROVEMENTS

FGR reduces peak flame temperatures, fuel bed and grate temperatures. As a result of this it prevents clinker formation and allows the use of a wider range of lower fusion fuels.

Calpenn’s customer list can be provided upon request.