

# APPLICATION OF HEAT RECOVERY AND POLLUTION ABATEMENT PROCESS

**Wayne Littleford, A.A.T. & M.E.T.**  
President & CTO  
Eco Power Solutions Corp.  
Stittsville, Ontario, Canada

**Sanjeev Jolly, P.E.**  
Vice President - Engineering  
Eco Power Solutions (USA) Corp.  
Louisville, KY

## ABSTRACT

This paper presents a seemingly simple and yet effective way of heat recovery and pollution abatement process that removes oxides of nitrogen and sulfur produced from exhaust gases of fossil fuel fired boilers, furnaces or chemical processes. The process involves diverting exhaust flow prior to release to atmosphere through the stack and treating these diverted gases to reduce their temperatures to near ambient and at emission levels that are much lower than those dictated by current air quality standards. The hot gases are directed through a flow through nozzle (aspirator) where they are mixed with an oxidant such as ozone in a preselected molar ratio to transform nitrogen oxide to a higher order of nitrogen to increase its absorbability in water. After ozone injection, the gases are then sprayed with peroxide/water mixture to absorb the oxidized contaminants from the exhaust gases. These gases then pass through a set of condensing coils where the transformed oxides are condensed on the coils as nitric and sulfuric acids along with some carbonic acid, which are then collected through a condensation collection system at the bottom of the coils. The resulting waste water stream consisting of diluted acids and particulates can then be suitably used or neutralized to form salts for discharge acceptable to municipality. An inherent byproduct of condensation process defined herein to remove pollutants also results in heat recovery in the form of hot water that can be transferred to boiler feedwater, air preheating, as a heat source in absorption chillers, etc. to improve plant efficiency and reduce operating costs.

## INTRODUCTION

The objective of this paper is to present a unique method of cleaning the exhaust gases from fossil fired units – coal, natural gas, wood-fired, municipal waste, etc. in a single process that surpasses traditional methods currently in use. The system can be designed in such a way as to offer only those features that are of value to the end-user. It could be just the heat recovery, emission reduction, particulate reduction, heavy metal removal or a combination of the above. This flexibility not only helps reduce the initial cost but also reduces the operating and maintenance costs, thereby maximizing the benefit to the client.

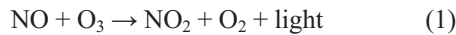
First, all the available features of the system are discussed in a step by step manner that describes how the technology works. It is a fairly simple and straightforward method replicating what nature does, but in a controlled environment where the harmful effects of the pollutants can be negated. Once all the desired pollutants are captured and condensed out of the flue gases, the wastewater can be suitably treated and disposed off. The application of this technology was successfully demonstrated with the help of a natural gas and two coal fired units installed at the company's facility in Louisville. At this facility, one can see simultaneous removal of multi-pollutants in addition to heat recovery benefits.

Typically, the flue gases consist of  $\text{NO}_x$ ,  $\text{SO}_x$ , particulates, etc. in various proportions depending upon the application. For natural gas units, there is no sulfur in the fuel and so  $\text{NO}_x$  is the primary pollutant in addition to particulate that are typically classified as PM 10 and PM 2.5.  $\text{NO}_x$  is formed

when nitrogen in the air reacts with oxygen at high flame temperatures. Another source of  $\text{NO}_x$  is the presence of nitrogen in the fuel which may react with oxygen in excess air. The fuel  $\text{NO}_x$  is not so much of a concern for gaseous fuels but could be significant for liquid or solid fuels. For coal or wood fired units, there is sulfur present in fuel in various quantities ranging anywhere from 0.5% to 6.0%. The undesirable oxides of sulfur,  $\text{SO}_2$  and to a lesser extent  $\text{SO}_3$ , are formed by oxidation of sulfur present in the fuel during the combustion process. These oxides when combined with water vapor in the atmosphere cause acid rain.

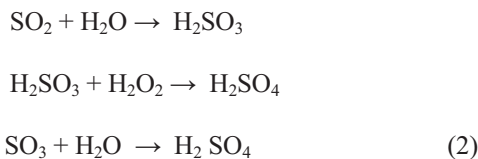
## METHODOLOGY

$\text{NO}_x$  primarily consists of  $\text{NO}$  and  $\text{NO}_2$ .  $\text{NO}_2$  is water soluble where as  $\text{NO}$  is not. So the first step in the process is to convert  $\text{NO}$  to  $\text{NO}_2$ . This is achieved by oxidizing  $\text{NO}$  with ozone. It is a simple reaction as follows:

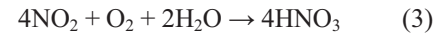


For a typical coal-fired application,  $\text{NO}$  ranges from 90 to 95% and remaining is mainly  $\text{NO}_2$ . Some higher oxides of nitrogen are also present but they are ignored here because they are in minuscule amounts that are also removed in the subsequent process. The location and amount of ozone to be injected is dependent upon flue gas temperatures and velocities. The residence time is a critical parameter that is often determined by rate of reactions and is temperature dependent. An excessive amount of ozone injection not only increases the size and cost of ozone generation equipment but may also result in undesirable ozone slip.

$\text{SO}_x$  consists of  $\text{SO}_2$  (~ 99%) and  $\text{SO}_3$  (~ 1%). This is addressed by first stage of foggers where a mixture of hydrogen peroxide and water is injected in the incoming gas stream. The reactions are as follows:



Injection of water at the first fogging stage also helps forms nitric acid as all the  $\text{NO}_2$  comes in contact with water.



In addition, to a lesser extent, the following reaction also occurs



After the first fog stage, a mixture of acids is formed primarily consisting of nitric and sulfuric acids along with traces of carbonic acid.

Downstream of the first fog stage, there are a set of condensing coils whose primary function is to reduce the flue gas temperatures below acid dew point to allow the acid mist as described above to precipitate out of the gas stream. The condensate collection system at the bottom of the unit collects these acids which also contains particulates and traces of heavy metals like mercury. In coal fired units, mercury is released as elemental mercury [2] in vapor phase. Elemental mercury is not water soluble whereas mercury oxide is. The acid mist after the first fogging stage along with hydrogen peroxide injected helps oxidize mercury that is subsequently removed in the condensation process.

Downstream of the first fogging stage and condensing coils is another set of fogging nozzles through which only water is sprayed in the gas stream followed by another set of condensing coils to ensure that any remaining acids/heavy metals are removed along with particulate matter. Again the condensation collection system at the bottom collects the precipitate consisting of diluted acids and lighter particulate matter from the exhaust gas stream.

See Figure 1 for complete schematic of the whole process described above. Another point worth mentioning is the reheat coil and induced-draft (ID) fan at the back-end of the unit. The insertion of reheat coil is optional. The exhaust gases coming out of the second set of condensing coils are saturated which may cause corrosion at the back-end of the unit in the outlet ductwork and stack unless they are lined with protective coating. In the absence of this protective

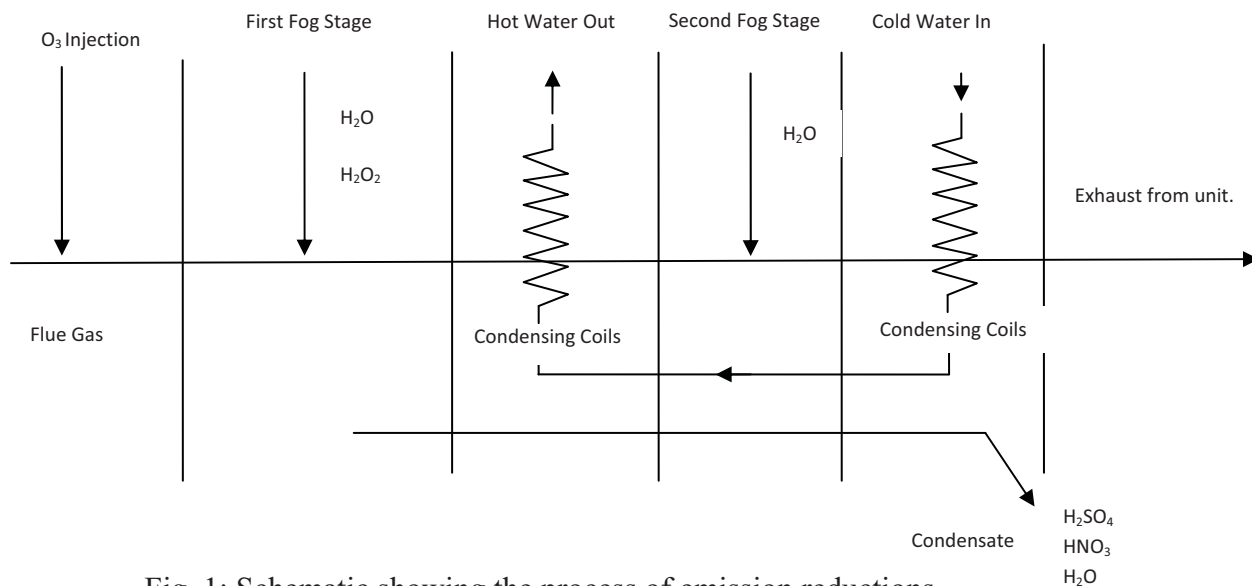


Fig. 1: Schematic showing the process of emission reductions.

coating, it is recommended to install reheat coils to dry the gases before discharging through the ductwork and stack to the atmosphere. The function of the ID fan is to overcome the pressure drop imposed by the system.

## WASTEWATER TREATMENT

As described above, all the undesirable emissions and pollutants from the exhaust gas stream end up in wastewater. It is much easier to handle containments in the water than in the gases. The water contains acids with a pH value ranging anywhere from 1.8 to 5.0 depending upon the emission levels in the gas stream. These acids need to be neutralized. There are various methods available – limestone, quicklime or caustic. Limestone is the preferred method because of its low cost as compared to other two reagents. The main advantage of caustic is that it can neutralize carbonic acid. When treated with limestone, the carbon dioxide in carbonic acid is released back which can be vented to the exhaust gases. When treated with limestone, the by product is salt and water as shown by the equations below:



The resulting salt can be compressed and dried up in the filter press and sent to landfill for disposal. The water can be routed back to the RO water system for treatment and reuse in foggers or as make-up water for condensing coils.

## DEMONSTRATION FACILITY

In order to demonstrate the effectiveness of the emission reduction and heat recovery system as described above, a demonstration facility was built in Louisville, KY. This facility covers 8,000 sq. ft of space and consists of one natural gas and two coal-fired units. The natural gas unit is employed to demonstrate both emission reduction and heat recovery applicability whereas the coal-fired units only demonstrate the emission reduction capability.

### NATURAL GAS UNIT

The 24 MMBtu/hr (7,034 kW) of natural gas burner generates 21,750 lb/hr (9,866 kg/hr) of gases at up to 1200°F (649°C). Downstream of the burner is a single pressure level waste heat boiler. It produces 4,200 lb/hr (1,905 kg/hr) of steam at a pressure of 700 psia (48.3 bars) and 600°F (315.6°C). Figure 2 shows a photo of the burner/boiler arrangement. The

purpose of the waste-heat boiler is to demonstrate the heat recovery capability and also reduce the gas temperature before entry into the unit. Figure 3 shows the routing of the ductwork from the waste heat boiler exhaust to the unit. Also shown is the aspirator for ozone injection and analyzer probe insertion location which is just upstream of the aspirator. This analyzer measures the inlet  $\text{NO}_x$ ,  $\text{SO}_2$ ,  $\text{O}_2$  and  $\text{CO}_2$  prior to the unit. Figure 4 shows the two COMPLY units – on the left side is the one for natural gas burners and the one on the right is for the two-coal fired units. The two stages of fogging arrays and condensing coils as well as ID fan are inside these units. The ID fan has VFD to save power consumption. The flue gases are routed through the outlet duct through a common stack where the downstream analyzer is installed to measure  $\text{NO}_x$ ,  $\text{SO}_2$ ,  $\text{O}_2$ ,  $\text{CO}_2$  and  $\text{O}_3$ . The function of downstream ozone measurement is to monitor ozone slip. The  $\text{CO}_2$  is measured at the inlet and outlet to demonstrate  $\text{CO}_2$  removal in the unit. The system is designed such that either natural gas or the two-coal fired units can run at any given time.



Figure 2: Natural gas burner with wasteheat boiler in the back.

## COAL-FIRED UNITS

The two coal-fired units are shown in Figure 5. Each unit is rated at 600,000 Btus (633,000 kJ) with a 20” (0.5 m) burn head and consumes 70 lb/hr (31.75 kg/hr) of stoker coal. Each boiler is connected through a common duct that routes to the inlet to the COMPLY unit. The inlet and outlet emissions are measured in the same manner as described for the natural gas unit above. The hopper stores about 1000 lbs. (453.6 kg) of coal. The feedrate is variable and is adjusted based on quality of coal. The efficiency of the boiler is dependent on the type of coal used. One can practically burn any type of coal and see the emission reductions in real time. There is no waste heat boiler here and the exhaust gases are directly fed to the unit after mixing with ambient air to reduce the temperature. The emission levels in ppm are representative of actual coal-fired boilers in power plant applications.



Figure 3: Aspirator in the inlet duct. Also shown are analyzer probes upstream.



Figure 4: COMPLY Units – NG on left and coal-fired on right.



Figure 5: Two coal-fired burners for demonstrating NO<sub>x</sub> & SO<sub>x</sub> reductions.

### MAJOR SYSTEM COMPONENTS

Brief description of major system components of the two units at the demonstration facility is as follows:

#### Ozone Generator

The ozone generator and chiller are shown in Fig. 6. The generator is capable of producing 70 lb/day (31.75 kg/day) @ 3% weight. The ozone cell utilizes a fixed voltage, variable frequency inverter in conjunction with precision electrodes. It has a 10:1 turn down from maximum ozone production with power consumption of 2.3 to 4.0 kWh per lb (1.04 to 1.81 kWh per kg) a day on oxygen feed {1.5 to 3%

concentration, operating pressure from 3 (0.2 bars) to 20 psig (1.38 bars)}. The required oxygen flow is 19.6 scfm (0.555 SCMM). Oxygen feed is taken from oxygen bottles as shown in Fig. 6. Ambient air can also be used as oxygen source but in this case, the generating capacity is reduced. For all industrial and power plant applications, we recommend using a pure oxygen source (90% or better) as feed for the ozone generator. The function of the chillers is to supply liquid for cooling the electrodes to minimize ozone thermal decomposition and reduce electrical power consumption.



Figure 6: Ozone generator with chiller on right and oxygen bottles on left.



Figure 7: Hydrogen peroxide storage tank with pumping station on left.

## Hydrogen Peroxide

The hydrogen peroxide required for SO<sub>2</sub> reduction for the coal-fired units is supplied from a 1,500 gal 50% concentration peroxide tank as shown in Fig. 7. It consists of two metering pumps, solenoid valve, pressure gauges and transmitters, pulse damper, back pressure valve and relief valve. The peroxide from this tank is diluted with water to a 2% concentration before injection in the first fogging stage. The 50% concentration peroxide consumption is 2 gph. The level in the peroxide tank is monitored remotely for replenishment and as a check against leaks, etc. because of its hazardous nature. It is placed outside the building in a fenced area with security cameras.



Figure 8: Analyzer location in outlet duct work to monitor downstream emissions.

## Emission Monitoring:

The emissions are measured upstream and downstream of the units to demonstrate the effectiveness of the units to reduce emissions. The measurements recorded are NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub> and downstream ozone. As described above, the location of the probes is upstream of the ozone aspirator and in the outlet duct downstream of the unit as shown in Figs. 3 and 8, respectively. The historian records all this data for review and analysis at a later date. These analyzers need frequent calibration almost on daily basis to assure reliability of measurements.

Therefore, it is important to have a steady inventory of various calibration gases.

## Heat Exchangers & Cooling Towers:

There are two heat exchangers – a shell and tube exchanger to show heat recovery from the condensing coils (Fig. 9) and a plate and frame exchanger (Fig. 10) to reject heat to the ambient through the cooling tower. They are referred to as primary and secondary heat exchangers, respectively. The cooling tower is shown in Fig. 8 and is placed outside in a fenced area. The shell and tube heat exchanger is used to heat feedwater for the waste heat boiler.

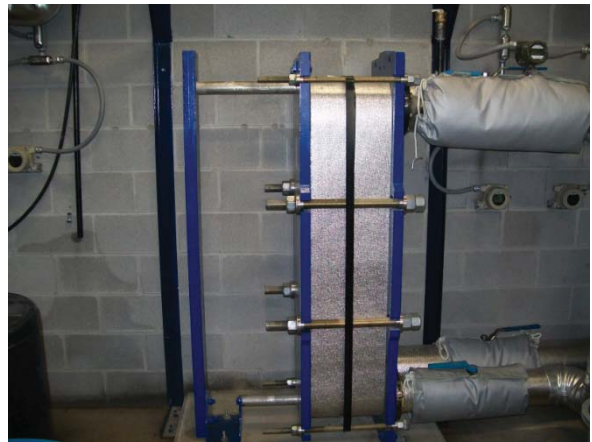


Figure 9: Secondary Plate & Frame Heat Exchanger.

## Reverse Osmosis (RO) System:

The RO system supplies process water to foggers and wasteheat boiler. See Fig. 11 for a photo of this unit and Fig. 12 for the RO water storage tank. The RO system has a micro-processor based controller and capacity to process 19 gpm of city water. There are five 300 psig (20.7 bars) non-code FRP pressure vessels with side ports and 15 thin film composite brackish water membranes. There is a multi-stage centrifugal pump and filter housing with 5 micron cartridges. The storage tank helps the boiler and units to run in steady state mode without having to



Figure 10: Shell and tube heat exchanger for rejecting heat to the cooling water.

frequently start and stop the RO system to meet the demand. This helps minimize wear and tear on the RO system and also allows extra time to shut-down the system in case RO permeate supply was lost.

#### **Foggers:**

The fogging skid as shown in Fig. 13 supplies high pressure water/peroxide to the nozzle arrays and is located inside the building. There are 2 positive displacement pumps on the skid. The first pump is custom designed to handle peroxide/water mixture.

Filters and regulators are located on the suction side as an added precaution for this delicate operation. The second pump is used for injecting water only in the second fogging stage of the process. The fogging skid and the ozone generator are located below the two units to save space.



Figure 12: RO water storage tank.



Figure 11: Reverse osmosis water skid.

#### **Wastewater Treatment:**

The condensate from the bottom of the units is routed to an equalization tank fitted with a high level switch, electric actuated valve and temperature sensor. The wastewater is then routed to the treatment tank where it is treated with caustic to control pH. The pH neutralization system is a single stage pH adjustment system consisting of a recirculation/discharge pump, chemical metering pump, multipoint level sensor, pH probe, flow switch and redundant high-level sensor. The treated water is then discharged to the drains per the water permit requirements. Although limestone is the preferred method because of its cost effectiveness, the decision was made to use caustic to demonstrate the effectiveness of system in capturing carbon dioxide. The entire system is completely automated with a programmable logic controller with ethernet communications.



Figure 13: Two pump fogging skid.

## Natural Gas Unit Results

The flow diagram in Figure 14 shows the natural gas application and is used to simulate both temperature and exhaust gas composition which would be similar

to an industrial application, where heat and exhaust gas characteristics would be generated from a natural gas casting furnace, melting furnace or any other type of process furnace or boiler.

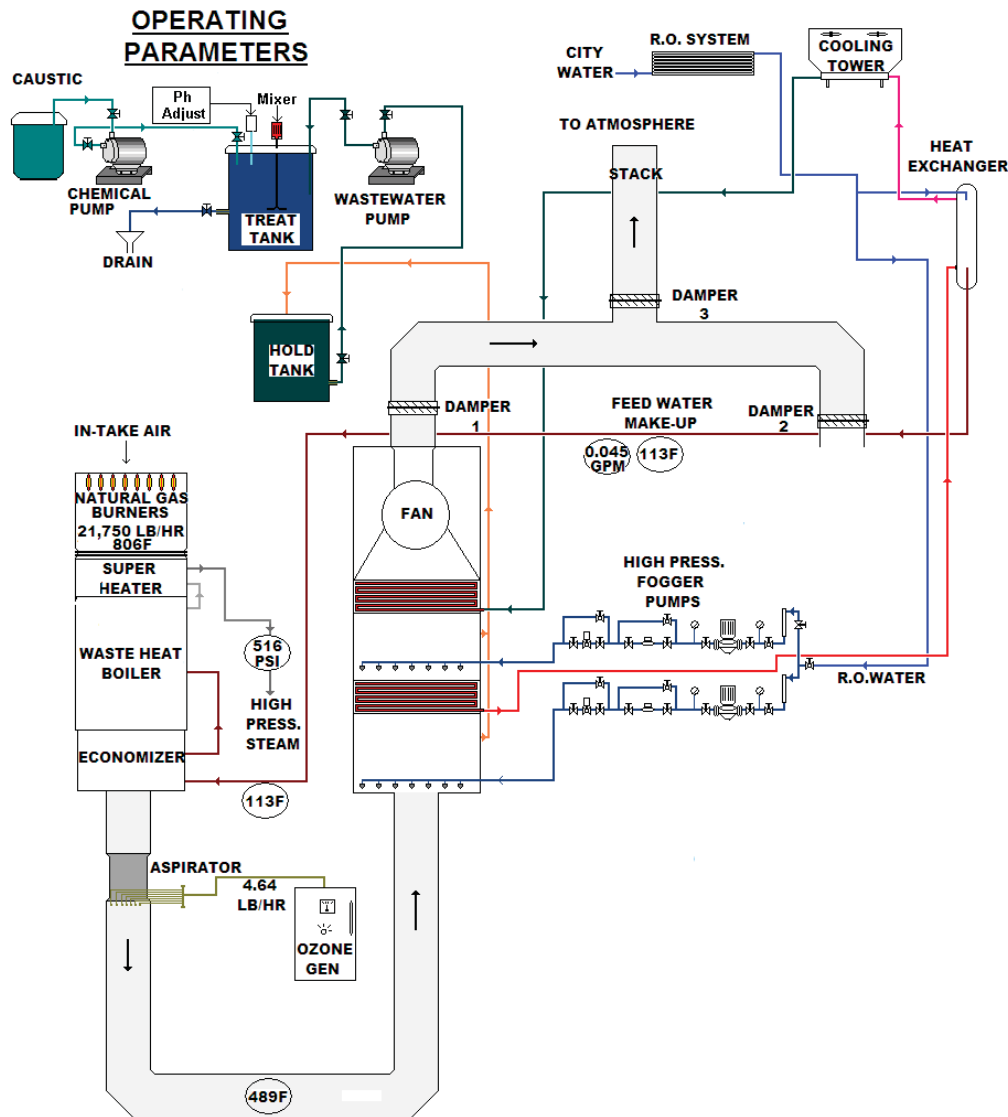


FIG. 14: Schematic of natural gas fired unit arrangement with NO<sub>x</sub> abatement.

Table 1 shows the % of NO<sub>x</sub> removed from the exhaust gases of natural gas unit.

Table 1: NO<sub>x</sub> removal rates for natural gas unit.

Date Time	O <sub>2</sub> Exiting Stack PPM	NO <sub>x</sub> Exiting Stack PPM	NO <sub>x</sub> from Burner PPM	% of NO <sub>x</sub> Removed
7/15/2010 15:27:39	17.95	0.01	3.12	99.63
7/15/2010 15:43:40	17.95	0.19	3.55	94.57
7/15/2010 15:47:52	17.95	0.19	3.50	94.49
7/15/2010 15:51:49	17.95	0.19	3.13	93.85
7/15/2010 15:55:45	17.95	0.19	3.52	94.53
7/15/2010 15:59:50	17.95	0.19	3.45	94.42
7/15/2010 16:07:45	17.95	0.19	3.55	94.57
7/15/2010 16:11:56	17.95	0.19	3.33	94.21
7/15/2010 16:15:55	17.95	0.19	3.48	94.46
7/15/2010 16:19:35	17.95	0.19	3.30	94.17
7/15/2010 16:23:56	17.95	0.19	3.30	94.16

**Coal-Fired Application:**

The coal fired unit arrangement is shown in Figure 15 and it is selected in such a way to simulate both temperature and exhaust gas composition of power plant application. Table 2 shows the results of the run conducted on July 22, 2010. Both the NO<sub>x</sub> and SO<sub>x</sub> reductions are listed. Please note that the analyzer actually measures SO<sub>2</sub> but the process of condensation also removes any SO<sub>3</sub> present as described in the methodology.

Table 2: Results of NO<sub>x</sub> and SO<sub>2</sub> removal rates from coal fired units. This facility is still new and more data is being recorded and analyzed. Higher rates are achievable than reported here as was demonstrated by studies conducted earlier at the Brookhaven National Labs [1]. We are in the process of enhancing system capabilities by increasing the firing temperatures on the gas-fired burners which will allow us to produce more NO. Higher NO also helps more efficient removal because the ozone aspirator was designed for higher injection rates. This will also help to reduce ozone slip in the exhaust gas stream to values below 60 ppb.

In the near future, our action plan is to do wastewater analysis to determine the acids collected and back calculating the amount of NO<sub>x</sub> and SO<sub>x</sub> removal and comparing these values to the ones obtained from the analyzers. Other objective of the wastewater analysis is to determine particulate and mercury removal.

We also plan on installing opacity meters in the exhaust ductwork to measure PM 2.5. Again earlier lab results showed that almost all the particulate end up in the wastewater as a result of the condensation process.

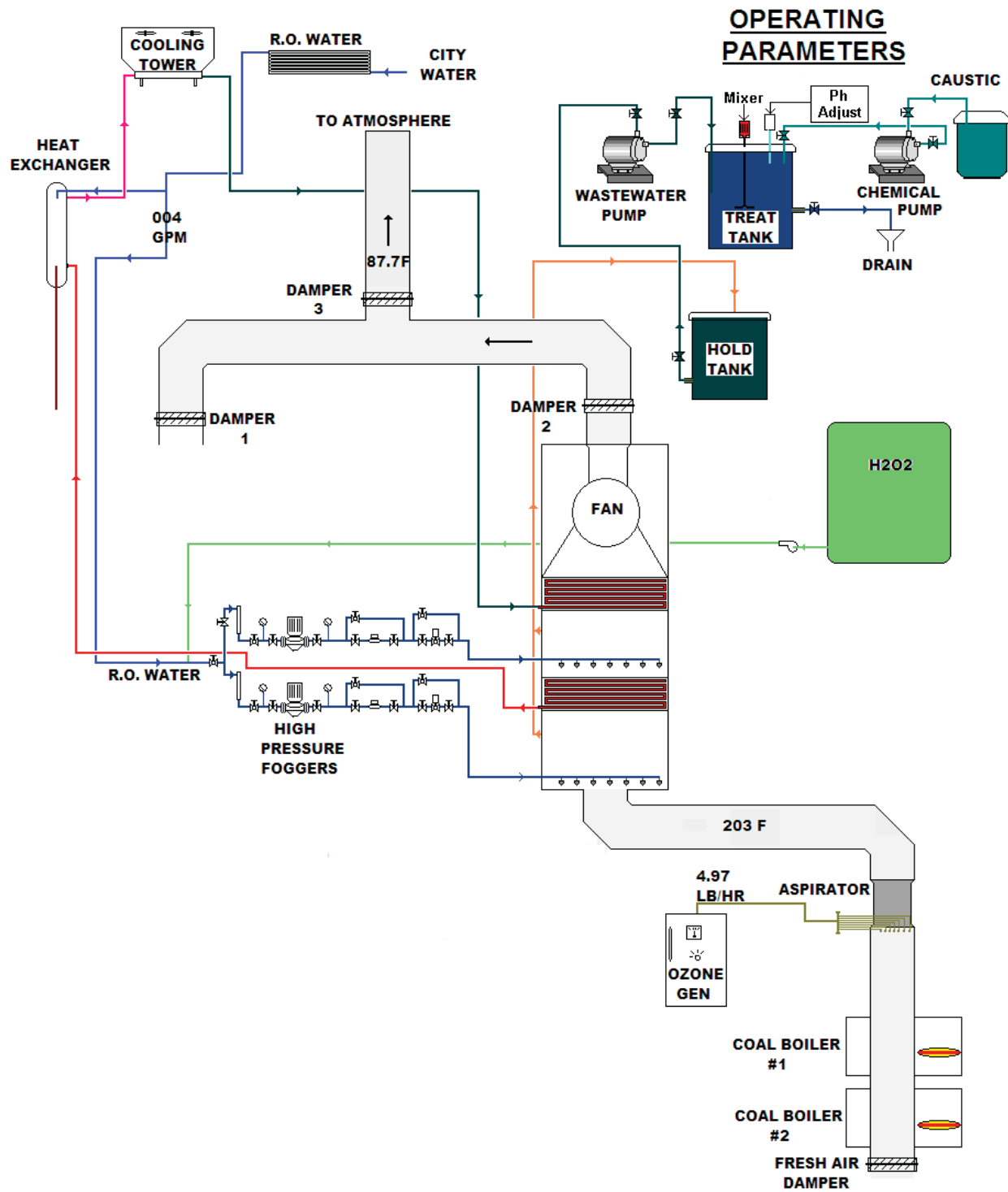


FIG. 15: Schematic of coal-fired unit arrangement with NO<sub>x</sub> & SO<sub>x</sub> abatement.

Table 2: NO<sub>x</sub> & SO<sub>x</sub> removal rates for the coal-fired units.

Date Time	O <sub>2</sub> Exiting Stack PPM	NO <sub>x</sub> Exiting Stack PPM	NO <sub>x</sub> from Burner PPM	% of NO <sub>x</sub> Removed	SO <sub>2</sub> Exiting Stack PPM	SO <sub>2</sub> from Burner PPM	% of SO <sub>2</sub> Removed	Ozone (ppb)
7/22/2010 14:41:19	20.24	1.70	30.96	94.52	7.92	277.80	97.15	76.62
7/22/2010 14:41:20	20.24	1.70	30.96	94.52	7.92	282.96	97.20	76.62
7/22/2010 14:41:36	20.24	1.70	30.98	94.52	7.92	282.96	97.20	76.62
7/22/2010 14:41:37	20.24	1.70	59.65	97.15	7.92	282.96	97.20	76.62
7/22/2010 14:41:43	20.24	1.70	59.65	97.15	7.92	282.96	97.20	78.26
7/22/2010 14:41:58	20.24	1.70	59.65	97.15	8.37	282.96	97.04	78.26
7/22/2010 14:42:00	20.24	1.70	59.65	97.15	7.99	282.96	97.18	78.26
7/22/2010 14:42:01	20.24	1.70	59.69	97.16	7.99	282.96	97.18	78.26
7/22/2010 14:42:02	20.24	1.70	48.77	96.52	7.99	269.71	97.04	78.26
7/22/2010 14:42:03	20.24	1.70	48.77	96.52	7.99	253.73	96.85	78.26

## CONCLUSIONS

In this paper, a new and alternative approach to emission reductions for fossil fired units is discussed. The process is based on converting the pollutants to water soluble compounds and then capturing the resulting acids in wastewater by condensation which

can then be neutralized by adding a suitable reagent. While the results show the reductions in the range of 94 to 97%, higher rates are achievable with slight modifications to the process. Reductions of over 98% were earlier demonstrated with a series of test conducted at Brookhaven National Laboratory and verified by independent third party agency.

## REFERENCES

1. Littleford, W. and Jolly, S., "An Innovative Approach to Emission Reductions and Heat Recovery", Paper No. GT 2010-23814, ASME Turbo Expo, Scotland, June 14-18, 2010.
2. EPA White Paper, "Control of Mercury Emissions from Coal-Fired Electric Utility Boilers"