Increasing Natural Gas Boiler Efficiency by Capturing Waste Energy from Flue Gas

Mark Schiffhauer, ATSI Engineering Services
Cameron Veitch, Combustion and Energy Systems
Scott Larsen, New York State Energy and Development Authority

ABSTRACT

A Stack Gas Heat Recovery System utilizing a condensing heat exchanger was designed, fabricated, and installed to recover the waste flue gas energy from a natural gas fired boiler. The recovered energy is used to preheat boiler makeup water and combustion air. Preheating makeup water, using the energy in the stack flue gas, increases boiler efficiency 6 percent to 8 percent annually. The Heat Recovery System is a dual-stage condensing economizer designed to conserve energy by preheating both boiler makeup water and a glycol solution. The first stage preheats boiler makeup water. The second stage heats a glycol solution used to heat combustion air. Combustion air, previously heated using direct-fired natural gas, uses "excess" heat available from the flue gas to eliminate the use of natural gas in the heater of the building air handler.

The Olin Niagara Falls Plant is part of the Olin Corporation Chlor-Alkali Division. The Niagara Plant produces chlorine, hydrochloric acid, bleach and caustic soda for industrial users.

The objective of the Stack Gas Heat Recovery system installation was to increase boiler efficiency, which in turn lowers cost of production. The cost reduction of the product comes from the reduction spent on natural gas to produce steam. The energy savings from this project were expected to be approximately $520,000 annually during the first 10 years of operation. Natural gas pricing used for economic evaluation was based on 2007 NYMEX natural gas futures, which at that time ranged from $9.96 per decatherm (MMBtu) in 2008/2009 winter to $8.01 per decatherm in 2012 summer.

This paper identifies the Heat Recovery System for capturing flue gas, describes the resulting energy savings, and discusses the progression of how the Heat Recovery System Project obtained the capital appropriations necessary to implement the project.

The goal of this paper is to encourage an interest from potential users to consider capturing waste energy that is otherwise vented up the stack and reuse this energy to increase boiler efficiency.

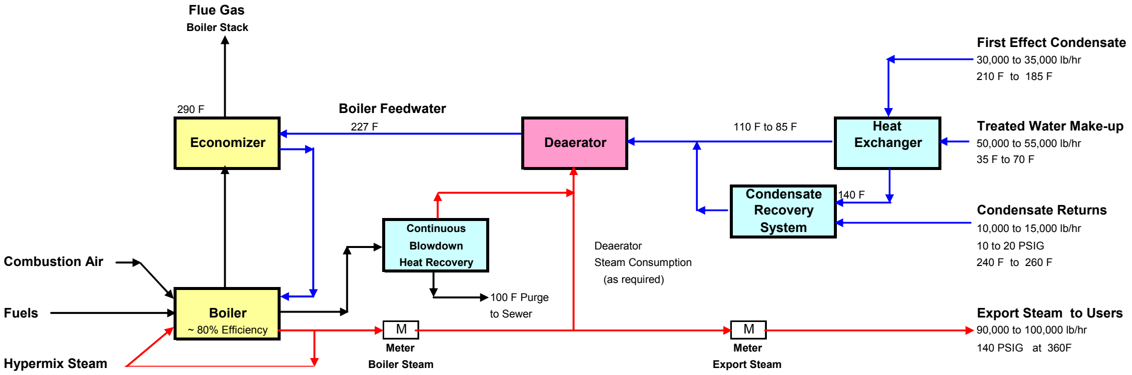
Introduction

Industrial process and heating applications continue to be powered by steam and hot water. The mainstay technology for generating this energy is the water tube boiler. Water tube boilers have proven to be highly efficient and cost effective in generating energy for process applications.

The Olin Niagara Plant utilizes two water tube Nebraska packaged boilers to produce saturated steam at 150 psig. Each boiler is rated at 75,000 pounds per hour steam capacity to provide steam for the process areas of the plant, as well as building heat. The boilers are fueled by "surplus" hydrogen and natural gas. Hydrogen is produced on site as a bi-product of the chlor-alkali process. Surplus hydrogen which is either not sold to customers or used within the process is used as fuel.

Boiler efficiency, or fuel-to-steam efficiency, represents the difference between the energy input (fuel) and energy output (steam). The Olin boilers utilize "best practice" systems to maximize overall boiler efficiency, which include; O_2-trim for combustion air control, "traditional" feedwater economizers to achieve 290 degrees Fahrenheit stack gas, boiler blow-down heat recovery, and steam condensate return. A schematic of these systems is shown in figure 1.

Figure 1. Boiler Schematic Diagram of "Best Practice" Systems



Despite these efforts, a significant amount of heat input to the boilers is still lost as both sensible and latent heat energy, contained in the 290 degrees Fahrenheit stack flue gas exiting the economizers. The boiler flue gas exiting the economizer still contains significant energy that can be recovered and used to heat other process requirements currently heated using natural gas and steam. Approximately 20 percent of the energy input to boilers is typically "lost" as water vapor and stack gas heat exiting the boiler economizers at approximately 290 degrees Fahrenheit. When natural gas is burned, 14 percent of the energy is lost because the hydrogen in the fuel combines with the oxygen in the combustion air and is instantly vaporized by the heat of combustion to form water vapor. The vaporization of this water consumes energy from the fuel that cannot be recovered and used effectively unless you condense the energy back out of the flue gas using a condensing economizer or similar method. For every pound of natural gas combusted, 2.25 pounds of water vapor is produced and for every pound of hydrogen combusted, 9 pounds of water vapor is produced.

If this energy can be captured and reused in the boiler process, the boiler efficiency can be increased. Given that 12 weight percent of the flue gas is water, at 15 percent excess air, a significant energy savings can be achieved through the recovery and use of this latent heat. When the water vapor is condensed, the latent heat is recovered at 980 Btu per pound and each pound will save one cubic foot of natural gas.

Olin chose an indirect contact condensing economizer to recover the heat from the flue gas. The indirect contact condenser prevents boiler make-up water from contacting the condensate from the flue gas and also allows the flue gas to be cooled below the dew point thereby extracting more heat. A condensing economizer is environmentally favorable because it reduces CO_2 emissions. The Heat Recovery System allows less fossil fuel to be burned causing a direct reduction in the CO_2 combustion product, and the CO_2 in the flue gas is absorbed in the condensed water vapor reducing gas emissions from the stack. For each million Btu of fuel saved, the emission of CO_2 is reduced by 118 pounds. The absorbed CO_2 and water provides an additional benefit in that it creates a mild acid (carbonic acid) that can be used neutralizing the boiler blow down solutions.

As in a typical boiler scheme boiler make-up water is heated in the Deaerator Tank (DA). The main function to the DA Tank is to strip dissolved gases from the water with steam prior to entering the boiler. The heat recovered by a condensing heat exchanger can offset much of the steam required in the deaerator to heat boiler make-up water. This offset will reduce fuel consumption while maintaining a fixed net steam output, or when required, it will increase the net steam output by maintaining the same fixed fuel consumption. Care must be taken not to elevate the temperature of the incoming make-up too high that no steam is required in the DA Tank or the stripping of gases from the boiler feed water will be ineffective.

Very few boiler installations use a condensing economizer to increase overall boiler efficiency. This technology has not been common practice in the boiler industry. Most industrial boiler installations use “traditional” economizer technology to achieve 290 degrees Fahrenheit to 300 degrees Fahrenheit stack gas temperatures and in the order of 80 percent to 82 percent overall boiler efficiency. When fuel costs were low, this heat was seen as minor. Today it is a major target for boiler system energy efficiency improvement. The industry was reluctant to use condensing economizers due to material costs, the requirement to keep the condensate from draining back into the boiler stack, and the risk of corrosion caused by condensation of sulfur containing stack flue gas. Using fuels such as natural gas that do not contain sulfur, and a condensing heat exchanger that utilizes stainless steel and aluminum construction can offer a cost effective means to recover stack gas energy.

As fuel costs increase, the addition of condensing economizers has been on the increase. Paybacks are often less than two years depending on the site specific installation costs, annual hours of operation, annual fuel costs and quantity of make-up water being supplied to the boiler.

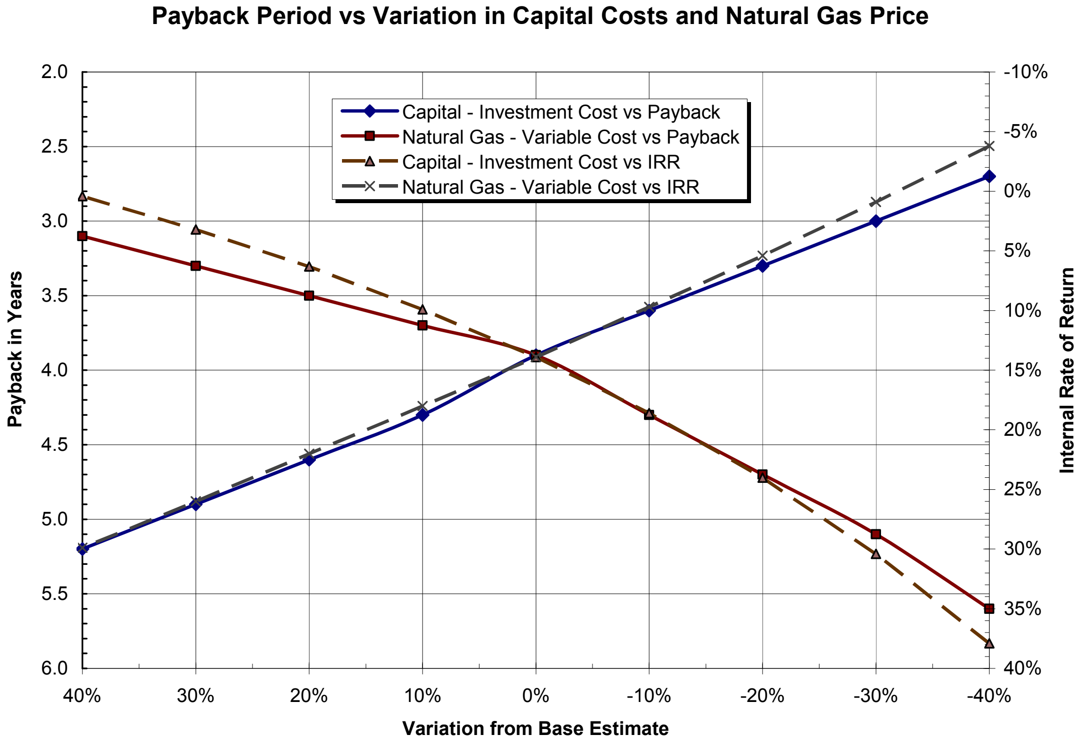
Investment Decision

The Olin Niagara Technical Department prepared a conceptual design of a Heat Recovery System and developed a cost estimate to evaluate the economics of the project. Budget quotes were obtained on major components and preliminary layouts were made for the new equipment within the existing boiler house.

The final capital appropriation request cost estimate for installing the Heat Recovery System at the Olin Niagara Plant was \$1.305 MM. The Olin Corporation capital investment guidelines require a payback period of no more than 3.0 Years for cost reduction projects. Olin also requires an Internal Rate of Return (IRR) during the first five years of at least 20 percent for these projects. Final project economics resulted in an estimated payback for the cost reduction project of 3.9 years an IRR less than 14 percent which did not meet the corporate financial thresholds for approval.

The economic evaluation looked at the sensitivity of payback and IRR to variations in the investment cost (capital) and variable cost (natural gas). Each has nearly the same result on the payback, with capital investment being slightly more prominent. The results of sensitivity analysis are shown in figure 2.

Figure 2. Simple Payback Sensitivity to Cost Variations



Olin Niagara applied for a $400,000 grant from New York State Energy Research and Development Authority (NYSERDA) proposing this project could be used as a demonstration of a new energy-efficient process for use in the industry. It was felt that this project could benefit other New York State industries by sharing the advantages and benefits of this system.

Concurrently, the appropriations request for the project was submitted to Olin Division based on not obtaining grant funding from New York State. During the approval process the project obtained NYSERDA grant funding and the project was approved. The funding received from NYSERDA weighed in on the decision to approve the project. Obtaining funding allowed the project to proceed without reduction in scope. Applying the grant to the project economics resulted in an estimated payback of 3.0 years and a five year IRR of more than 30 percent which meet the corporate financial thresholds for approval.

The Olin Niagara plant operates in an environment of high regulation and cost. The need to identify timely opportunities that reduce plant operating costs and position the plant to improve existing compliance with environmental regulations is critical. This project presented an opportunity to accomplish both at a time when energy costs and attention to greenhouse gas emissions are increasing. The ability to partner with NYSERDA in support of this project was critical to its success. This project provided a benefit to Olin Niagara to control costs of production, and at the same time, demonstrate environmental stewardship.

System Design

The essential component of the Heat Recovery System is the flue gas condensing heat exchanger. The condensing heat exchanger, called ConDex, was supplied by Combustion Energy Systems Ltd of Markham, Ontario. The ConDex unit maximizes water vapor condensation and the resulting recovery of both latent heat and sensible heat from the flue gas.

The condensing heat exchanger uses a single gas pass to remove both sensible and latent heat from the boiler flue gas. The flue gas enters the heat exchanger through an inlet plenum at the top and flows downward across the horizontal banks of heat exchanger finned tubes and exits the heat exchanger through an outlet plenum on the bottom of the heat exchanger and up a stack.

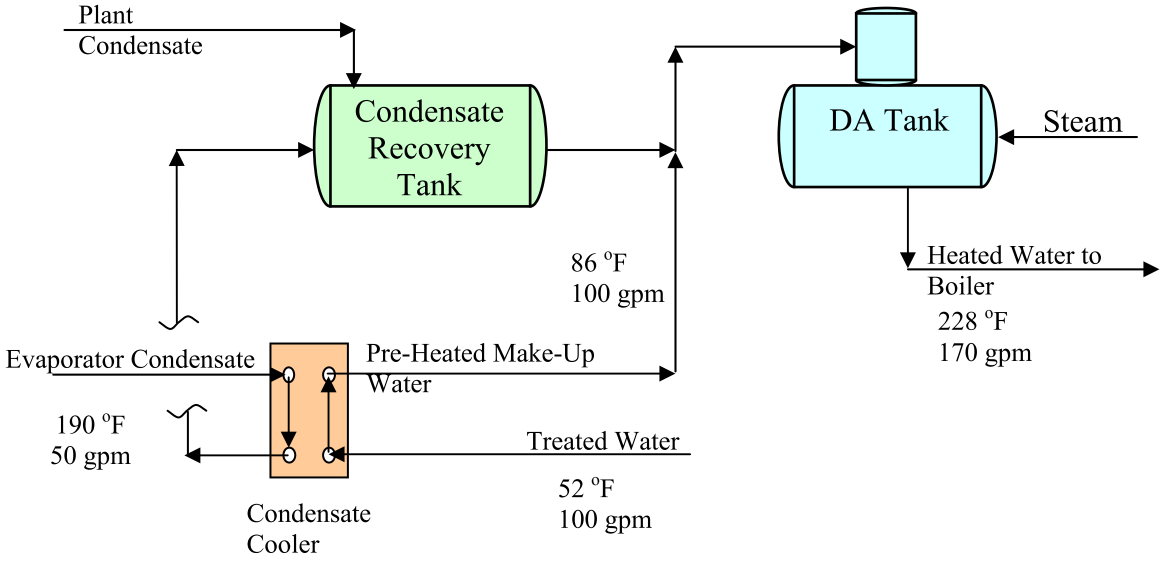
Construction of the ConDex exchanger consists of stainless steel tubes and aluminum fins to increase the heat transfer surface area of the unit. The aluminum fins are a special metallurgy that has excellent corrosion resistance to carbonic acid formed when flue gas moisture is condensed. The combustion product CO_2 is absorbed in the condensed water vapor to produce the carbonic acid.

Total boiler capacity is 150,000 pounds per hour, with each boiler being capable of producing 75,000 pounds per hour. The ConDex design was based on a steam load rate of 90,000 lbs/hr, equating to 80,150 lbs/hr of flue gas at 290 degrees Fahrenheit, and 110 gpm of makeup water. This was the average winter load of the past two years. Although the boilers will experience peak loads greater that this, it would not be cost effective to design the recovery system to peak winter loads. The fuel mixture used as the design basis was 50 percent hydrogen and 50 percent natural gas.

It is critical to contact the flue gas in the condensing exchanger with the coldest make-up water, the colder the better. The optimal transfer of energy from the flue gas is in the condensing of the flue gas water vapor. To accomplish this, the existing boiler flow scheme would have to be modified.

One of the initial energy conservation systems in the original boiler system was pre-heating the make-up water to around 90 degrees Fahrenheit in a plate and frame exchanger using returned condensate from the caustic evaporator. Cooling the pressurized condensate prior to its discharge into the atmospheric Condensate Recovery Tank prevents the condensate from flashing. If the condensate is allowed to flash, the energy is lost in the tank vent. Capturing the energy from the condensate and transferring it to the make-up water prior to its addition to the DA Tank increased the boiler efficiency in the original design (figure 3). The figure shows average values during winter operation.

Figure 3. Original Make-up Water Pre-Heating Flow Diagram Average Winter Conditions



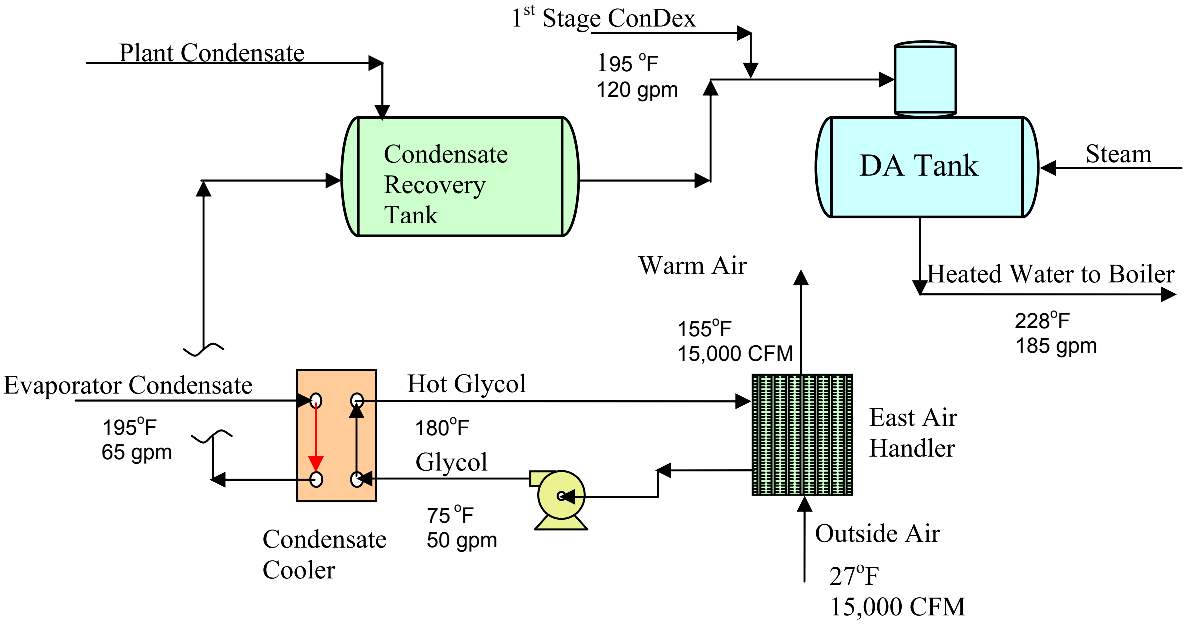
The "Latent Heat of Vaporization" mentioned previously consumes approximately 14 percent of the energy in the fuel (and can range up to 19 percent depending on site specific operating characteristics). In order to actually use any of this energy that is paid for, the heat energy must be released from the flue gas. To release and recover the maximum amount of energy, the most effective way is to contact the flue gas with as much cold water as possible. Contacting the flue gas stream with 86 degrees Fahrenheit pre-heated make-up water in the ConDex would have resulted in a larger area exchanger, and not released and recovered as much latent heat energy. A warmer inlet water temperature results lower heat transfer rates to cool the flue gas to its dew point. The dew point temperature of the flue gas is about 137 degrees Fahrenheit and the flue gas has to be lowered to that temperature and beyond before any condensing occurs, therefore; the condensate cooler would not be used in the ConDex design.

The downside in re-routing the makeup water away from the condensate cooler would be the lost energy from the flashing condensate. In the energy balance the loss of energy at the condensate cooler would have taken away from the recovered energy at the ConDex unless another use was found to cool the condensate.

The combustion air for the boilers is supplied from two air handlers, east and west, that feed outside make-up air to the boiler house. In the winter the air handlers heat the incoming air using natural gas. This provides heat to the building and warms the air up prior to the entering boiler. Combustion air temperature effects boiler efficiency. A 40 degree variation in ambient temperature can affect efficiency by 1 percent or more. If the energy from cooling the condensate could be transferred to the make-up combustion air the condensate system boiler efficiency could be maintained and the energy originally transferred to the make-up water will now be transferred to the combustion air.

To achieve this, a Glycol Circulation System was included in the design. This system circulates a glycol solution from the condensate cooler plate and frame exchanger to a new heating coil installed at the building air handler. In this design condensate in the Recovery Tank will be maintained at 200 degrees Fahrenheit ± 5 degrees Fahrenheit, using the glycol to cool the condensate returned from the evaporator. This temperature will minimize condensate flashing but not cool the condensate to the point it would have to be reheated unnecessarily in the DA Tank. Combustion air, previously heated using direct-fired natural gas in the air handler, now uses the heat from the hot glycol to warm the air. A new coil was installed on the air handler where the make-up air passes over the coil before entering the boilerhouse. The scheme is shown in figure 4 and is identified as the East Glycol Circulation System.

Figure 4. East Glycol Circulation Flow Diagram

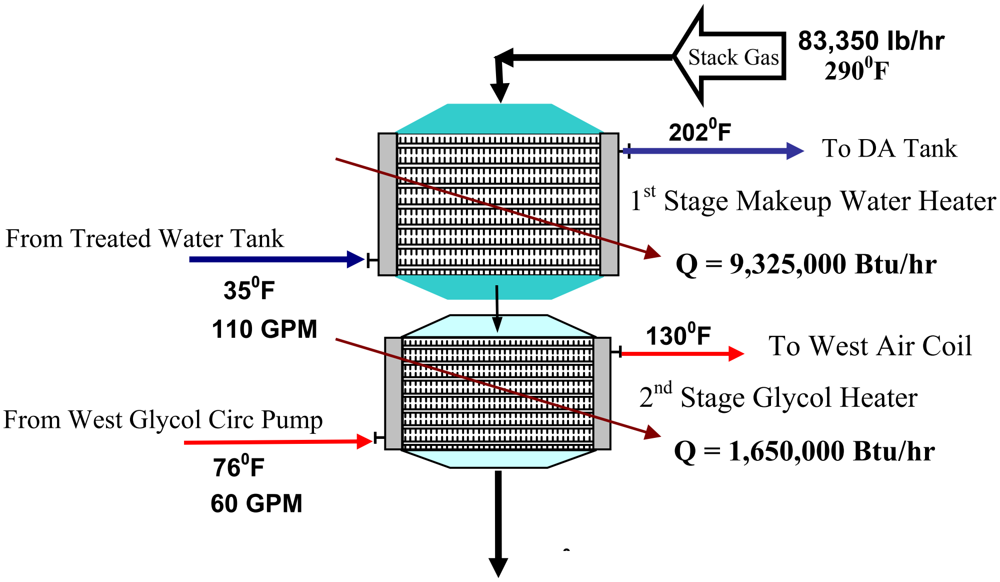


In the Olin boiler operation 40 percent to 50 percent of the steam produced is returned to the boiler as condensate. This means roughly half of the water fed to the boiler is make-up water. As a result there is excess energy in the flue gas after the first stage of the condensing economizer. To take advantage of this excess energy, a second stage exchanger was included in the ConDex unit to circulate a second glycol stream.

The design basis energy balance for the two stage ConDex is shown in figure 5. These conditions are based on the winter steam load of 90,000 pounds per hour with a fuel mixture of 50 percent hydrogen and 50 percent natural gas.

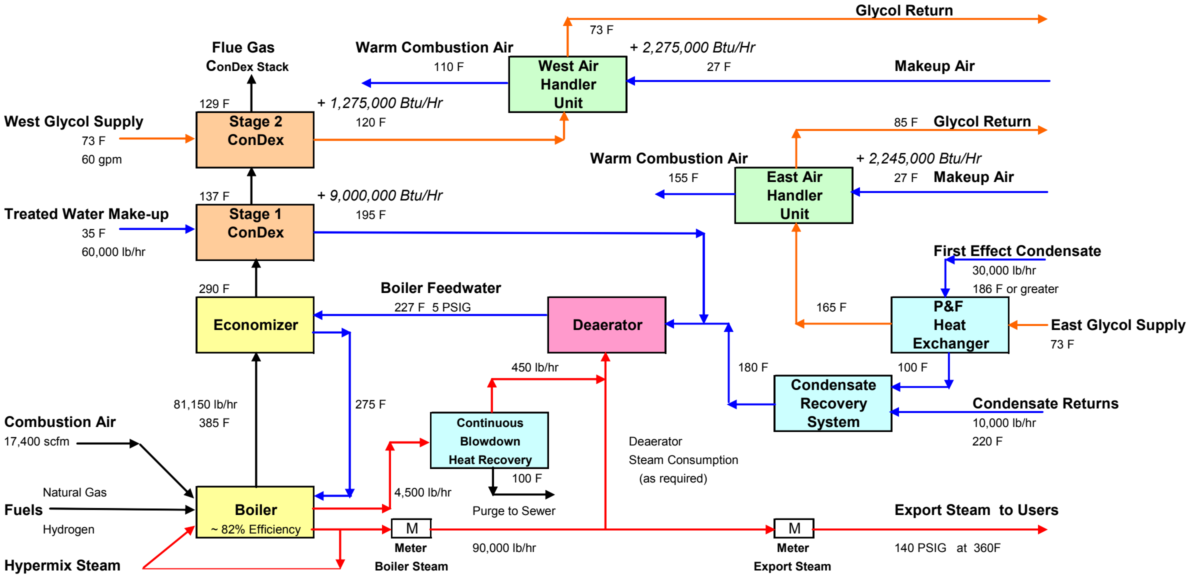
The west glycol circulation package, consisting of transfer pumps, piping, surge tank, air coil and instrumentation was installed to support the ConDex second stage. This system uses the west air handler to transfer the heat to the building air. A finned tube coil was installed on the west air handler and the glycol heated from the ConDex is circulated in a closed loop through the west air coil to heat the incoming cold winter air.

Figure 5. Design Basis for Two Stage ConDex Condensing Economizer



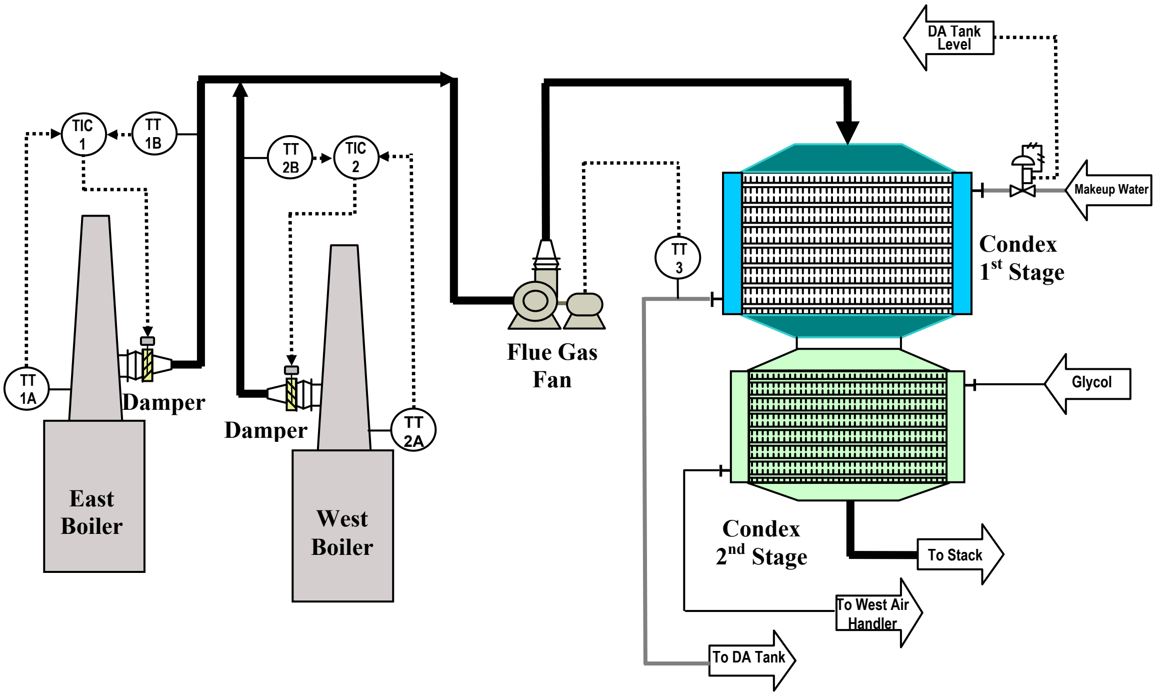
Combining the ConDex Condensing Economizer Heat Recovery Unit with the East and West Glycol Circulation Loops, the boiler efficiency is expected to gain 6 to 8 percent. The estimated heat that will be recovered within these units is shown in figure 6.

Figure 6. Boiler System with ConDex Heat Recovery and Glycol Circulation



The Condex was designed to operate in conjunction with the existing boilers and will not impair their operation. A schematic diagram of the ConDex Unit is provided in figure 7 to show the controls between the boiler and the ConDex. With the boilers on at any load, water will be introduced into the Condex 1st stage exchanger and the induced draft fan is started. The variable frequency drive on the fan motor will adjust with the boiler loads to maintain a negative pressure at the inlet duct of the boiler stack(s). This pressure and the modulating dampers will capture the flue gases throughout the operating range of the boilers.

Figure 7. Schematic Diagram of the Condex Unit



The treated water flow will be elevated in temperature to 195 degrees Fahrenheit in the 1st Stage. This is the design temperature at the boiler steam load of 90,000 pounds per hour and make-up water flow of 110 gpm. Should the water flow decrease while the boilers are on full load, the fan motor speed will decrease to maintain the make-up water outlet set point temperature. The dampers will automatically reset to maintain a pre-selected temperature difference between the flue gas from the feedwater economizer and gas to the ConDex.

When the boilers are on low load with a 110 gpm water flow, the water will be heated in direct proportion to the amount of flue gas available. When the boiler increases to a load above the design flue gas flow, the excess flue gases will not be conveyed to the ConDex exchanger as the supply fan will be at its maximum capacity. These gases will exit via the existing boiler stacks.

Implementation

The ConDex package was specified and bid shortly after the project was approved. Detailed engineering design began after equipment drawings were received.

ATSI Engineering Services, a full-service consulting engineering firm specializing in industrial facility design and modifications, provided structural, civil, and mechanical design for the project. ATSI provided the construction documents for installing the ConDex unit and its support equipment. Final design was completed in the 3rd Quarter of 2008. Civil, mechanical, electrical and insulation work scopes were prepared and issued for bid. Western New York based contractors were required for civil, mechanical and electrical installation of the equipment.

Construction activities, such as installation of foundations and building erection, were completed in August 2008 to support equipment delivery. Mechanical equipment and piping installation was completed in December 2008 with commissioning and start-up occurring in the first quarter of 2009. The system was turned over to Operations in March 2009 and put on-line.

A challenge in any retrofit project is the integration of a new process into an existing one. This project was no exception. In order to install the Heat Recovery System, tie-ins in the boiler house to the existing stacks and make-up water piping were required. The Plant operates 24/7 and unscheduled outages adversely affects plant operations, increase the cost of the project, and reduce the savings. Project design and execution had to accommodate installing the tie-in piping and ductwork during a five day plant outage. The plant has a scheduled outage once every two years. The stack and piping tie-ins were made during the May 2008 outage to allow the Heat Recovery System to be installed and connected when the equipment arrived later that year to minimize boiler operation.

Tie-in to the existing boiler stacks were made and sealed closed until the dampers and ductwork was installed. Makeup water lines were modified with isolation valves to allow new piping to be installed without interruption of flow to the boiler.

Evaluation of Results

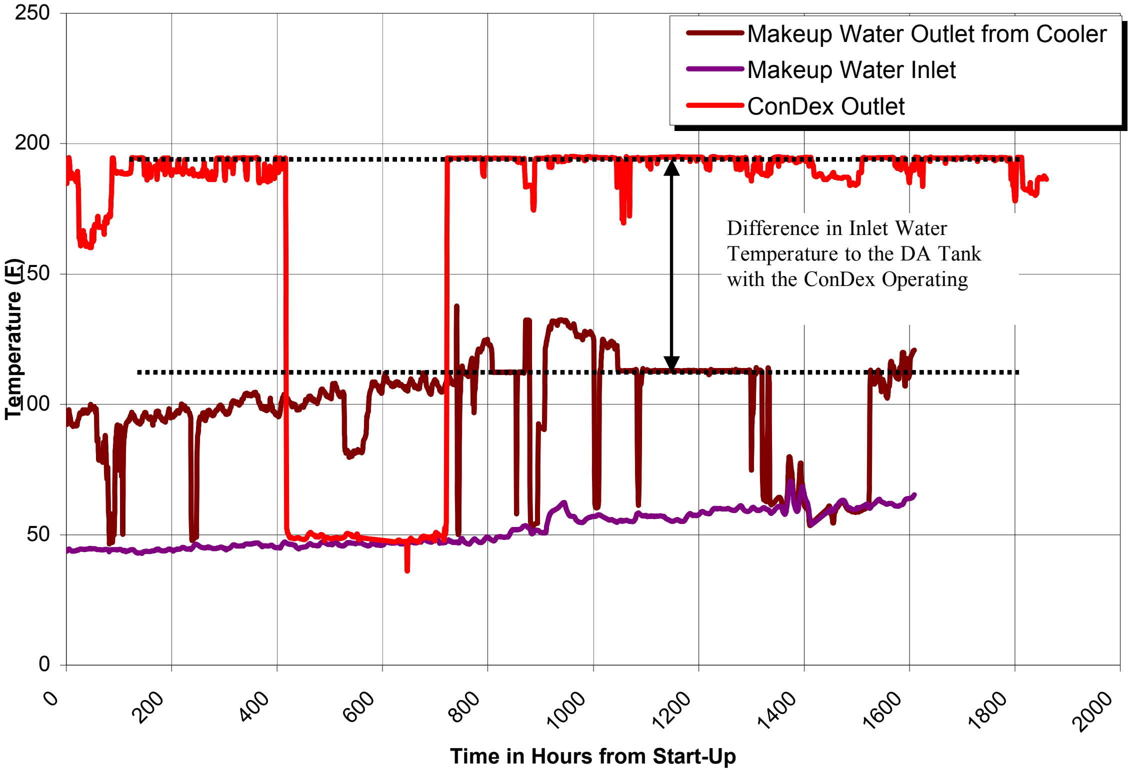
The Stack Heat Recovery System began operation in March 2009. After startup the boiler make-up water inlet temperature was 38 degrees Fahrenheit and the outlet temperature hit its set point of 195 degrees Fahrenheit as the system reached steady state. Make-up water flow was 78 gpm resulting in energy transfer of around 6,125,000 Btu per hour. The west glycol circulation loop added another 450,000 Btu per hour to the air handler inlet air.

Operating date form the ConDex is logged in the plant data collection system. Operating date will be compared to historical date to measure energy savings. As shown in figure 8, the make-up water entering the DA Tank from the Condex is 100 degrees Fahrenheit more that the water entering the tank last year on the same dates.

As the Heat Recovery System gains operating history, fuel consumption and steam production will be measured and compared to historical consumption to evaluate savings. The results will demonstrate lower energy use, which in turn lowers cost of production. The strategy for quantifying the actual project benefits is to track actual natural gas consumption in the boiler house per unit of steam delivered to plant users.

Modifying the boiler system to provide boiler make-up water heating via the ConDex condensing heat exchanger allows “excess” energy currently available from the condensate collection system to be used to heat combustion air entering the building.

Figure 8. Boiler Make-Up Water Inlet Temperature to DA Tank Comparison Between Last Year and ConDex Start-up



Conclusions

The objective of this project was to reduce the cost of production by reducing the amount spent on natural gas to produce steam and building heat. The energy savings from this project were projected to be approximately $520,000 annually during the first 10 years of operation. The average annual fuel savings is based on seasonal gas pricing and seasonal fuel savings, with winter months representing highest natural gas pricing and highest ConDex energy savings. Natural gas pricing used for the economic evaluation was based on a range from $9.96 per decatherm in winter to $8.01 per decatherm in the summer based on 2007 NYMEX natural gas futures.

Incorporating the ConDex into the Olin Boiler System increases the steam plant efficiency of the original design by 6 to 8 percent. In the winter months, when natural gas is a premium, the steam plant efficiency is 8 to 10 percent. Table 1 provides a listing of the estimated energy savings and CO_2 reduction that occurs at design conditions in the winter season.

Table 1: Estimated Energy Savings Under Design Loads
Average Winter Conditions

		Increased Steam Plant Efficiency	CO_2 Reduction Lbs/hr
Boiler Operation			
Steam Production	90,000 lbs/hr		
Boiler Efficiency	81.9%		
Fuel Load	94.6 MM Btu/hr		
ConDex	Energy Savings		
Make-up Water Heating	9.5 MM Btu/hr	9%	1,370
Combustion Air Heating	1.5 MM Btu/hr	1%	215
West Air Handler			
Natural Gas Savings	1.3 MM Btu/hr		185

The Olin Niagara Heat Recovery System will be a model installation of how existing industrial boiler systems can be retrofitted with stack gas “condensing” heat exchanger technology to improve overall thermal efficiency by 6 percent to 8 percent. The savings credited to the Heat Recovery System is directly based on the price of the fuel, the amount of fuel saved, hours of operation and fuel to steam efficiency.

The bottom line benefit of this project is that it helps Olin Niagara to control costs of production. In an increasingly competitive market, it is imperative that costs are stabilized or lowered. The Niagara Plant consumes large quantities of energy essentially as a raw material for production and the viability of the plant is directly tied to obtaining low cost power and minimizing energy consumption wherever possible.

The potential for replicating or commercializing these results in New York State is high. Retrofits of existing boiler operations such as presented in this paper can be effectively implemented and cost effective. Incorporating a condensing economizer in a new boiler installation would be especially cost effective and should be considered in boiler system design. A condensing economizer can be effectively implemented to achieve improved boiler efficiency, reduced boiler operating costs, and reduced CO_2 emissions.

NYSERDA supported this project through their Industrial Research, Development and Demonstration Program Opportunity program in the form of a grant. This support provides a conduit for the technology transfer and wider awareness of this energy efficient product to other potential users in New York State. This modification can be adapted to any facility that has a natural gas fueled boiler operation.

Olin will provide presentations, fact sheets, articles, case studies and/or provide on-site visits of our boiler facility. We are very pleased and proud of our grass-roots boiler facility constructed in 2003 and the addition of the ConDex Stack Heat Recovery System. Olin is open to sharing this with others interested in achieving Boiler energy efficiency and environmental improvement. We will work closely with NYSERDA and Combustion and Energy Systems accomplish this.