Feature Story

Del Monte's Super Boiler:
Ultra-efficient unit bears fruit, reducing emissions

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The majority of steam boilers operating today are based on designs developed in the 19th century, a period when highly polluting heavy oil was the most available fuel. Engineers at the time were more concerned about preventing acid corrosion and maintaining convective passes of air heaters and economizers than optimizing efficiency. As a consequence, most boilers operating today have efficiencies that are less than 81 percent.

Such low efficiencies have a significant impact on the country's energy consumption, since approximately 40 percent of all the energy used in America is consumed in boilers. The importance of boilers in our energy mix, the volatility of energy costs and the increased emphasis on reducing carbon footprint have combined to heighten the urgency to improve boiler efficiency and emissions. This has spurred research and development toward the so-called "Super Boiler": an ultra-high-efficiency, ultra-low-emissions compact gas-fired packaged boiler originally conceived of by the U.S. Department of Energy.

At the Del Monte Foods plant in Modesto, Calif., the Super Boiler concept has become a reality. The company has developed an innovative new boiler system that is not only helping its plant meet – and exceed – California's stringent greenhouse gas reduction targets but is also serving as an example for other local food processors.

Super Performance

As envisioned by the DOE, the Super Boiler has a fuel-to-steam efficiency that exceeds 93 percent while emitting nitrogen oxides at no more than 5 ppm. Attaining this level of efficiency is no small feat given the thermodynamic lim-

Courtesy Del Monte Foods Modesto.

Del Monte Foods' Super Boiler flue gas condensing heat exchanger has a boiler fuel-to-steam efficiency exceeding 93 percent.

its of the process. More than 10 percent of the energy evolved from the combustion of natural gas is locked up in the form of water vapor. Hence, efficiency cannot be increased above 90 percent without condensing some of the water vapor in exhaust, which, given the dew point of 130-138 degrees F, limits the available heat sinks.

Progressive Thinking

It stands to reason that such an efficient application would be of interest to companies located in areas with special environmental concerns. The same topography that makes California's 450-mile-long Central Valley the most productive agricultural area of the nation also contributes to the area's classification as a severe ozone nonattainment zone by the U.S. Environmental Protection Agency. In the effort to reduce the area's ozone levels, the San Joaquin Air Pollution Control District (SJAPCD) has subjected owners of steam boilers in the Central Valley to the nation's strictest limits on NOx emissions at 6 ppm. California is the only state to draft legislation mandating a 20 percent reduction in carbon dioxide emissions through a combination of market-based incentives and energy efficiency rebates.

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After being notified in 2003 of the 6 ppm NOx limit, Jim Mortensen, Del Monte Foods' plant manager in Modesto, in the heart of the valley, realized that to meet all future NOx and CO_2 emission mandates, the Super Boiler would have to become reality. Thinking progressively, Mortensen set about to make his steam plant upgrade the first to demonstrate Super Boiler steam-generating performance using commonly available technologies.

The Modesto plant was originally built in 1968 to process tomatoes. During the four-month pack, the facility's two 155,000-lb/hr D-type boilers would run near full load, providing steam used to evaporate water from juice to form tomato paste. Starting in 1995, the SJAPCD restricted NOx emissions from boilers to a concentration no greater than 30 ppm corrected to 3 percent. Aware of substantial problems associated with low-NOx burner retrofits, Mortensen and his chief boiler operator, Ed Connor, decided to research low-NOx installations on boilers of similar size and design.

Low-NOx burners were typically designed to inject the fuel farther into the firebox, the lower temperature of the longer flame resulting in lower NOx emissions. Recirculating around 20 percent of the stack gas volume back into the combustion air, the low-NOx burners were able to meet the required limit, but not without complications. The different flame pattern of the new burners often resulted in reduced boiler steam output, a consequence that the Modesto facility could not afford.

Mortensen and Connor discovered an alternative to burner replacement that used essentially the same amount of recirculated flue gas. The new technology relied on a far more accurate control of combustion air to reduce NOx by lowering the available oxygen needed to form NOx. In 1996, the Modesto facility opted to retrofit its boilers with the Compu-NOx system: a fuel, air and flue gas recirculation control system that used variable-speed drives instead of dampers to closely match combustion air and recirculated flue gas to burner fuel flow.

In addition to meeting the NOx limits and maintaining capacity, the near-stoichiometric combustion resulted in higher fuel-to-steam efficiency. While most facilities considered the expense to meet NOx emissions targets a sunk cost, the Modesto facility realized a simple payback within one year.

In 1998, Del Monte Corp. decided to convert the Modesto facility into a fruit-processing plant, resulting in a substantial change in steam demand. Operating year-round, Del Monte's new fruit cup line required between 2,000- and 40,000-lb/hr 60 psig steam. The can cookers used to process fruit during the summer harvest season used up to 150,000 lb/hr of 145 psig steam.

The facility staff realized that the boiler plant was significantly oversized for providing the wide variation in steam demanded of the new fruit lines. Analysis of steam plant operation data confirmed that one of the large 155,000-lb/hr boilers with its unprecedented 75-to-1 turndown could provide the steam needed by the fruit cup line – but there was a significant 'excess-air' efficiency penalty due to the distribution of fuel around the large burner circumference.

The fuel-to-steam efficiency for the average 10,000-lb/hr steam that needed to be delivered to the fruit cup line was only 70 percent. Given the deadline to meet lower NOx emissions in 2004, the facility decided that the most cost-effective solution would be to decommission one of the existing boilers and replace it with a boiler better matched to the plant's actual steam demand. After careful consideration of the existing loads, Del Monte decided optimum capacity of the new boiler would be 50,000 lb/hr.

Near-Zero NOx Emissions

The SJAPCD created an incentive for boiler owners to retrofit to the new lower NOx limits in 2003. Those owners who retrofitted their boilers by 2004 would be allowed to emit 9 ppm, which could be met with ultra-low-NOx burners, while those who waited an extra year would be required to meet 6 ppm – most likely requiring selective catalytic reduction (SCR). The high amount of recirculated flue gas required of the ultra-low-NOx burners to maintain emissions in the single digits severely impacted flame stability, which typically limited turndown to no more than 3-to-1. That fact – combined with the significantly reduced boiler capacity resulting from using ultra-low-NOx burners – motivated Del Monte to retrofit its boilers with SCR.

SCR involves the placement of a catalyst within the exhaust gas stream of the boiler. Ammonia is mixed with the exhaust gas flowing through the catalyst, causing the reduction of NOx. The technology is capable of reducing NOx emissions to near zero.

> Selective catalytic reduction technology is capable of reducing NOx emissions to near zero.

Del Monte knew that while today's limit may be 6 ppm, continued high pollution levels in the valley would most likely result in the imposition of lower emission limits for its boilers. Accommodating for this scenario, the facility decided to specify an SCR that would deliver a 5 ppm NOx reduction with an incoming NOx level of 50 ppm. Lower NOx could be attained by merely adjusting the Compu-NOx to deliver lower NOx to the catalyst.

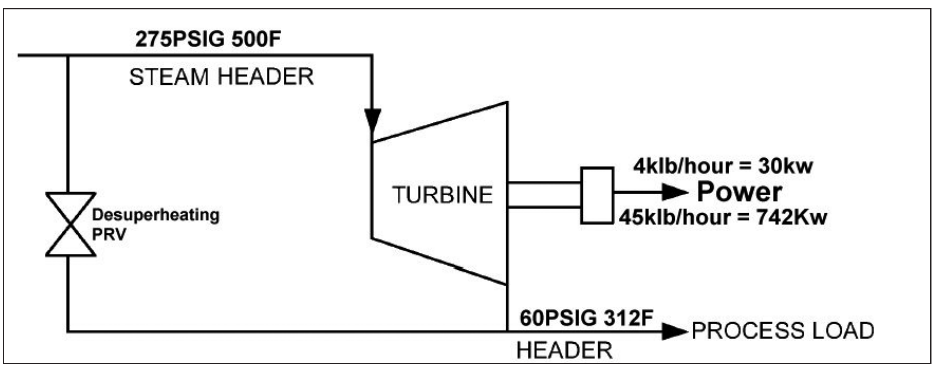
Generating Electricity for Less

The local utility had been raising Del Monte's electricity rate needed to process fruit every year, with electricity projected to exceed 12 cents/kWh by 2010. Mortensen and his staff looked to dampen the effect of these regular rate increases, recognizing the electric-generating potential from using a back-pressure turbine to provide steam to the 60 psig header feeding the fruit cup line. A feasibility study was conducted to find the optimum steam conditions to specify for the new boiler, concluding with 275 psig and 494 F and the back-pressure steam turbine generating electricity for less than 2 cents/kWh.

Del Monte hired TurboSteam of Turners Falls, Mass., to provide a payback analysis and a price quote for a turbine generator with financing. TurboSteam supplied a package design comprising a single skid with one induction generator that guaranteed 77 percent efficiency over a 10-to-1 turndown. The steam turbine would be installed with a desuperheating valve to maintain steam pressure in the event of turbine trip or at extreme low-load conditions (fig. 1).

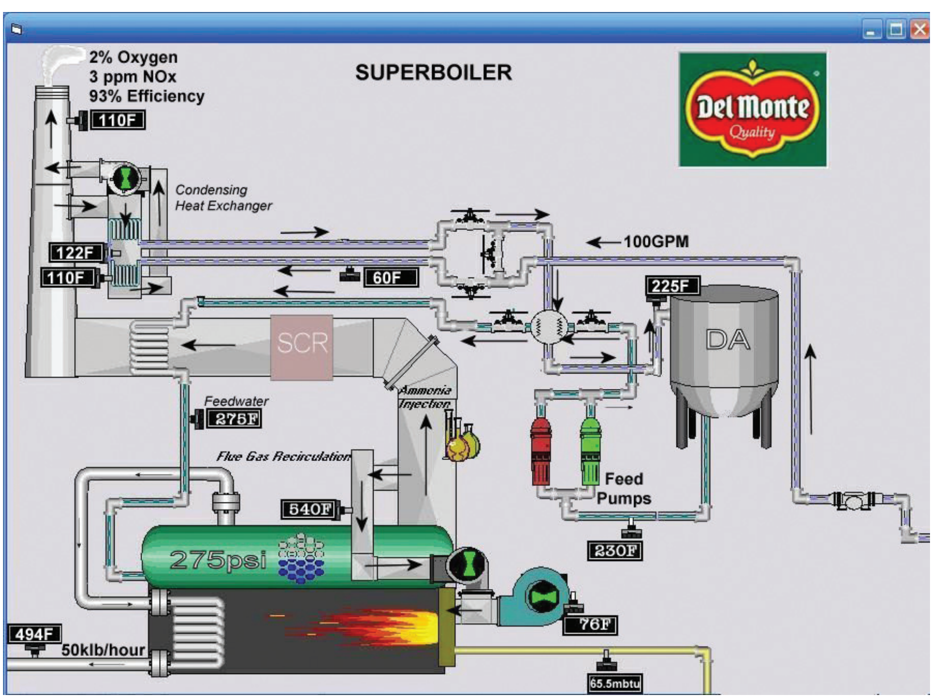
The operational data also served to establish a baseline of steam system efficiency that would be compared to the efficiency resulting from the upgrades. Rebates available from California's energy efficiency rebate program would increase the return on investment from the lower cost of operation resulting from efficiency.

Figure 1. Back-Pressure Steam Turbine, Del Monte Foods' Super Boiler.



Source: Benz Air Engineering

Figure 2. Del Monte's Super Boiler: Full-Load Boiler and Heat Recovery Process.



Source: Del Monte Foods Modesto.

Incorporating Stack Gas Heat Recovery

Only a small amount of condensate from the steam to the new processing lines could be recovered, the majority of the 60 F makeup water being preheated with process steam in the deaerator. The process also required a substantial amount of hot water, which was also heated with process steam. Recognizing these various sources represented a substantial heat sink, Mortensen enlisted Benz Air Engineering Co. to design and incorporate a heat recovery system into the new boiler project.

A pinch analysis of preheating boiler makeup and process water using boiler flue gas heat recovery was used to design a condensing heat exchanger. The resulting design (fig. 2) integrated the condensing heat exchanger into the boiler system, which, when combined with the control system, yielded some novel features that would result in efficiency exceeding 93 percent:

- Installation of an additional heat exchanger between the makeup water and the feed water provided significant reduction in the needed heat transfer of the condensing heat exchanger.

- The condensing heat exchanger design was an active draft system, imparting no change to the boiler combustion system. This design feature is particularly important due to maintaining the boiler air-fuel ratio at lower loads while allowing bypass of the system during operation.
- The counter-flow design – in which the condensed products of combustion flow downward opposite the direction of the makeup water – prevented the re-evaporation quenching of flue gas. This maintains the humidity ratio of the flue gas, optimizing the heat transfer to the makeup water.
- Flue gas condensate collected within the dropout volume under the downstream stainless coil is pumped back to the makeup water line coming out of the upstream coil, contributing up to 7 percent of the total makeup water flow to the boiler.
- Capacity for preheating up to 50 gpm of process or makeup water was added. 110 F saturated flue gas still contains nearly 7 percent of the total energy input to the boiler. The additional flow capacity of the last coil would increase efficiency to 94.5 percent.

System Control and Optimization

The supervisory control system was designed based on an Allen-Bradley ControlLogix platform. The system allowed for combustion control with additional control added for feed water flow control, makeup water flow control, SCR ammonia flow control, condensing flow control, feed water-to-makeup water flow control, steam superheat control and the emission-monitoring system control. A proportional-integrative-derivative controller was developed for the human machine interface, running on a PC platform and written in Visual Basic.

The control system relied on variable-frequency drives for controlling the various flows throughout the system. While each of the water flow loops had venturi-based flow measurement, the system control using variable-frequency drives greatly simplified the system control over that of using setpoint control.

Economic Justification

Mortensen finalized the steam system upgrade of his facility, which comprised the following:

- 50,000-lb/hr boiler designed to provide 275 psig steam 494 F superheat with a conventional burner provided by Nationwide Boiler
- combustion control system provided by Benz Air Engineering
- SCR system provided by Nationwide Boiler, sufficiently sized to reduce NOx from 50 ppm to less than 5 ppm
- back-pressure steam turbine, provided by TurboSteam, to generate up to 750 kW of electricity from the expansion of 40,000-lb/hr 275 psig, 494 F steam to 60 psig
- flue gas condensing heat exchanger provided by Benz Air Engineering, sized for preheating up to 150 gpm from 65 F to 146 F using 12,400 standard cu ft per minute flue gas entering at 175 F and 2 percent excess oxygen and 10,200 scfm leaving at 101 F, resulting in 7.8 gpm of additional condensate
- supervisory control system integrated with the combustion control system for seamless integration of external components through remote racks, programming and design provided by Benz Air Engineering

The back-pressure turbine was financed over 10 years with an upfront down payment and a yearly cost of $68,000. The cost of the steam plant upgrade was estimated to be $1,665,000, which included 14 percent additional contingency due to the novel aspects of the proposed system. The baseline energy costs included natural gas at $8/MMBtu and electricity at $0.07/kWh. Subtracting a $262,000 rebate from Pacific Gas & Electric, the total upfront cost of the upgrade was $1,403,000, resulting in a simple payback of 3.85 years.

Verified Results

The project commenced construction in fall 2006, and the system was commissioned in June 2007. PG&E performed an energy audit of the system that verified a boiler fuel-to-steam efficiency of 94.5 percent, the higher efficiency resulting from preheating additional process water needed by the plant.

Del Monte Foods Modesto demonstrated a design for other food processors to duplicate. A subsequent increase in the efficiency rebate offered by PG&E from $8 to $11/MMBtu saved over the year prompted Pacific Coast Producers, Seneca Foods and SunOpta to install boiler upgrades using the same technology pioneered by Del Monte. This resulted in a total verified reduction of 5,582 metric tons of CO_2 per year, which would be equivalent in greenhouse gas savings to the following:

- 1,211 passenger cars not being driven for one year
- 715 households not using electricity for one year
- 143,163 tree seedlings grown for 10 years
- 635,909 gallons of gasoline
- 48 acres of forest preserved from deforestation

The obsolescence of pneumatic control systems with far more powerful microprocessor-based control systems has generally separated the field of energy engineering into either electrical or mechanical engineering. In some cases, this compartmentalization of expertise has severely hampered the efforts of district energy managers to implement efficiency upgrades. The success of the Del Monte Modesto Super Boiler project is primarily a result of management's sourcing design and engineering to individuals possessing a broad-based knowledge of heat transfer, combustion and control system engineering.

Robert P. Benz, PE, is president of Benz Air Engineering Co. Inc. With more than 27 years of experience in combustion engineering, Benz supervises the implementation of combustion control solutions for maximum efficiency and lower emissions for central plants. He pioneered the use of variable-speed drive technology of fans for precisely metering air flow, a process for which he was granted a U.S. patent. Benz holds a bachelor of science degree in mechanical engineering from Oregon State University and is a registered professional engineer in California, Nevada and Texas. He may be reached at RBenz@benzaireng.com.

