Gas Turbine NOx Reduction Retrofit

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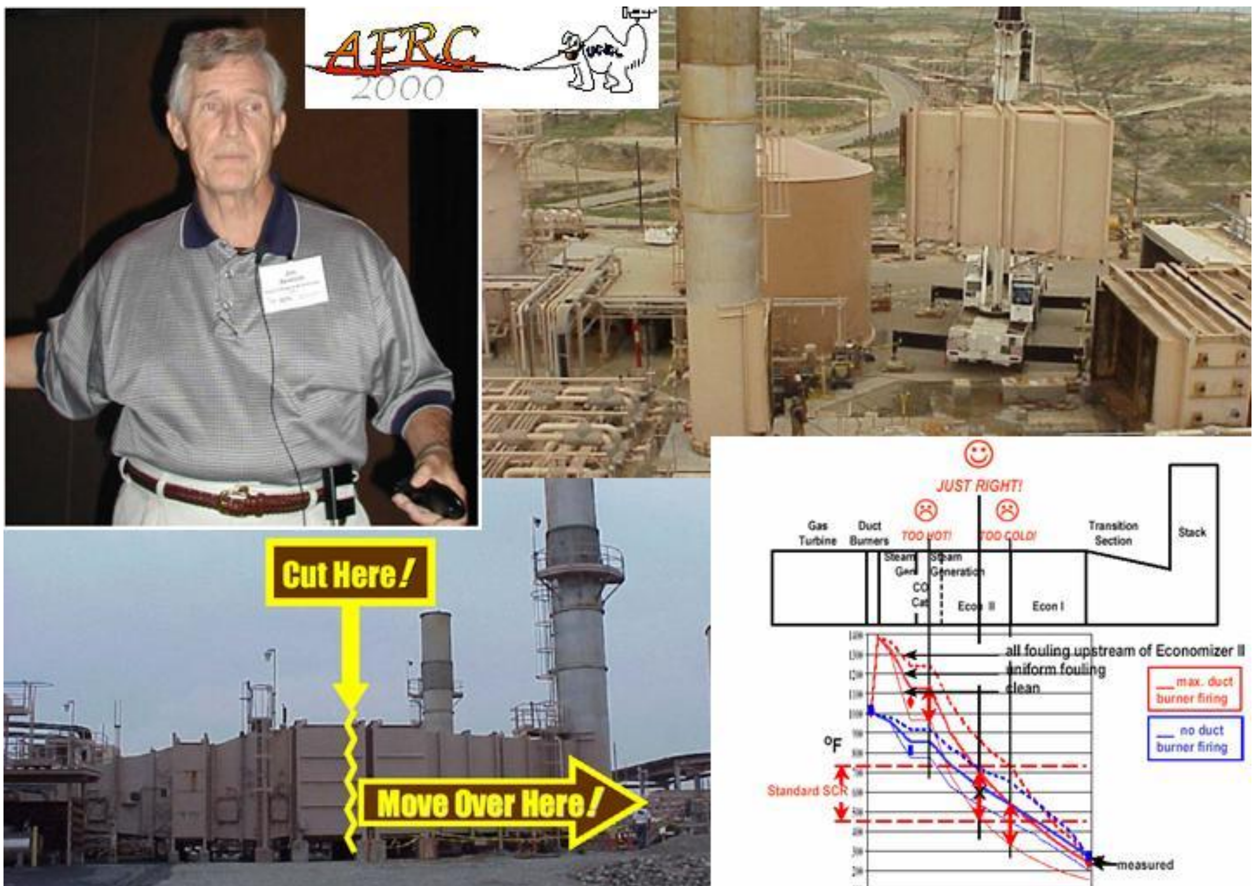

Figure 1: Overall View (before) showing the general concept of the field work.

Figure 2: Thermal model showing field measurements before (♦, ■) and after (X) the retrofit. Note the perfect match with the desired SCR reaction tempera-

Abstract

Chevron's Eastridge Cogeneration Plant, located in the San Joaquin Valley in the Kern River Field near Bakersfield, California, produces steam for thermally enhanced oil recovery and electricity to the utility grid. To meet San Joaquin Valley Air Pollution Control District NOx emissions rules, two General Electric LM2500 combustion gas turbines needed the addition of selective catalytic reduction (SCR) flue gas treatment systems. This "major surgery" retrofit project sets a benchmark for effective decision

analysis, front-end-engineering and safe, smooth field execution. Looking to the future beyond the current rules, the equipment is sized and ready to go to comply easily with future reductions.

This paper briefly describes the process from beginning to end. Those who may face such retrofits in the future but lack experience or who would like to improve their previous performance may benefit from Chevron Eastridge's learnings. With good planning, gas turbine SCR retrofits can be accomplished at reasonable cost and with minimal disruption to energy operations. The project's identification and qualification of a full-service *domestic* SCR catalyst supplier, fully capable of supplying all catalyst services importantly including catalyst activity testing (*anybody's* catalyst), benefits all Chevron operations both upstream and downstream with existing or future SCRs; no longer must service be provided from Japan. Thus, the project is pleased not only to have met and exceeded its own goals but also to have been of service to the entire corporation. Shutdowns limited to a stunning 5 days for major field modifications minimized the disruption to electricity and steam supply and kept both external and internal customers happy. Completed ahead of schedule and under budget, the 11-month project and 63-day construction spans were remarkable by any standard***!***

Introduction

At the Eastridge Cogeneration Plant, two General Electric LM2500 combustion gas turbines needed selective catalytic reduction (SCR) flue gas treatment systems to meet San Joaquin Valley Air Pollution Control District NOx Emissions Rule 4703 requiring reduction of the current <42 ppm NOx emissions to <12 ppm (71% reduction). By looking to the future, the equipment was sized to readily meet foreseeable emissions limits. Only the installation of additional catalyst material and increased ammonia flow (extra space in the reactor module and extra pump capacity provided) will be needed in order to achieve emissions as low as_<3 ppm or 90% reduction. Peerless Mfg. Co.,America's leading SCR system supplier, was awarded the turnkey contract to design and supply the SCR equipment; ARB Inc. was selected by Peerless to carry out the construction. The team's project management, design, field service and design support were outstanding. Completed ahead of schedule and under budget, the 11-month project and 63-day construction spans were remarkable by any standard. Shutdowns were limited to a stunning 5 days for major field modifications thatminimized the disruption to electricity and steam supply and kept both external and internal customers happy. Here's a thumbnail sketch of the major field modifications:

- Prior to shutdown dug and poured new foundations, some under existing ducts
- Shut down the unit and moved the boiler feedwater metering skids
- Decommissioned and abandoned in place tube rows at the end of Economizer II to get the right SCR reaction temperature
- Cut the duct between economizers
- Moved and set the stack, duct and Economizer I (the latter requiring a 90 ton jack and roll) on new foundations to make room for the SCR reactor module and new downstream economizer (to the regain steam generating capacity lost in Economizer II tube abandonment)
- Installed empty SCR reactor module and new economizer (60 ton lift)
- Buttoned the whole thing back up and started generating electricity and steam again at the old permit condition, while system checks were performed
- Loaded catalyst and started the ammonia upon completion of the ammonia flow control skids and all monitoring and control instrumentation upgrades

The project's identification and qualification of a full-service *domestic* SCR catalyst supplier will benefit all Chevron operations both upstream and downstream with existing or future SCRs. Fully capable of supplying all catalyst services importantly including catalyst activity testing (*anybody's* catalyst), Cormetech Inc., Durham, NC aspired to become the world's leading SCR catalyst supplier and, with the acquisition of a huge Tennessee Valley Authority contract has pretty much achieved that world class status. No longer must service be provided from Japan. Thus, the project is pleased not only to have met and exceeded its own goals but also to have been of service to the entire corporation.

Thermal Modeling

Accessing the optimum catalyst reaction temperature is the key to NOx reduction performance for any SCR retrofit. Accordingly, during the front end engineering phase, the project contracted with TechnipUSA to do various conceptual studies including a flue gas thermal model. Shown schematically in Figure 2 are the thermal modeling predictions together with the actual field measurements and physical locations along the length of the flue gas path. For reference, a photograph of Unit B as shown in Figure 1, is in the same orientation as the schematic in Figure 2.

As shown, predictions were made for both no duct burner firing and full duct burner firing and, for both, under clean and two fouled heat transfer surface conditions. There was good agreement with actually measured temperatures. Not surprisingly, the units were found to be operating somewhere between "clean" and "uniform fouling" and closer to the latter.

Inevitably, it seems, the optimum catalyst temperature range for so-called "standard" SCRs (*ca.*500°F-750°F) is found somewhere in the *middle* of one of the heat recovery sections and so it was in this case. This implies major surgery and heavy-duty component rearrangement. So, being well-experienced with the use of "Low Temperature" SCR (*ca.*350°F-500°F) designs[1], we looked carefully at the much *physically* cleaner LTSCR option during the front end engineering phase of the project. Regretfully, the flue gas temperature was simply too low (*i.e.*, the cogeneration plant is simply "too" efficient) for a simple end-of-pipe design to work effectively; and, the reheat, re-recovery option with which we are, regretfully, also well-experienced made neither economic nor constructability sense.

Similarly, the easily-accessible upstream temperatures were simply too high for application of "high temperature" SCR technology. Accordingly, the project proponents buckled down to a major surgery, hammer and tongs, brute strength and awkwardness twin field retrofit and got after it.

Safety, Total Cost and Environmental Cost-Effectiveness

Despite the fact that the Eastridge retrofit demanded complex heavy-lift cramped-quarters field construction, the entire project was carried out with zero incidents or accidents. This is attributable to an excellent Safety Plan developed at the outset that was consistently reinforced by management and enthusiastically supported by all hands.

The total "all-in" cost of the project to the stockholders (including all company costs) was $3.25-million. But in computing the environmental cost-effectiveness, it is important to recognize that advantage was taken of the opportunity to completely modernize the facility by upgrading the turbine controls, control room displays and other infrastructure. Those improvements are unrelated to NOx emission reduction and their cost is appropriately *excluded* to get a fair assessment of NOx reduction cost-effectiveness. Restricting attention to the environmental portion of the project, the total installed cost of the SCR retrofit including all company costs was $2.3-million.

The annualized total installed cost ($/yr), which in the San Joaquin Valley is taken to be amortized at 10 years and 10% rate of return, is 16.3% of the total installed cost ($). For SCR, annual operating costs and annual maintenance costs are nearly negligible (by comparison) and are commonly taken to be 10-20% and ~5%, respectively, of the total installed cost. Thus, annual operating and maintenance costs typically increase the annualized total installed cost ($/yr) by 15-25% or to 0.19-0.20($) so we shall take 0.195($) to estimate the annualized total cost of ownership ($/yr) = 0.195x$2.3-million = $448,500/yr.

The annual NOx reduction (tons/yr) being achieved by the Eastridge units is 350 tons/yr. The cost effectiveness ($/ton) then becomes the annualized total cost of ownership ($/yr) divided by the annual NOx reduction (tons/yr) = $1,281/ton.

Many NOx reduction regulatory mandates have been carried out at *much* higher (*i.e.,* less favorable) cost-effectiveness. While the project's environmental cost-effectiveness is exemplary, regulators and others will do well to remember that cost-effectiveness is merely a figure of merit that may be used to facilitate comparison with *other* means of achieving the *same* NOx reduction mandate or with the environmental effectiveness of *other* projects.

"Cost-effectiveness" *per se* hardly drives the business decision and *never* provides, in and of itself, financial justification for project execution. It is true, however, that for a given regulatory mandate, the project planning process that produces the lowest total cost of ownership (annualized capital cost plus annual operating and maintenance costs) will also produce the lowest environmental cost-effectiveness.

In any event, considering that individual environmental projects ideally contribute some measure of health or wellbeing improvements, they do not directly affect the corporate bottom line. Thus, public stockholders and corporate directors alike favor NOx reduction projects that are carried out at the*lowest* possible cost-effectiveness***!***

Project Development and Execution Tools

At this point it seems useful to step back to the early conceptual days of the Eastridge project to mention briefly the various project management and development tools that were used to good advantage in producing a winner for stockholders and the consuming public alike. Not least among these was "DA" (Decision Analysis) which answered the question, for example, "Given the variety of NOx reduction technologies that are available, which ones are technically and economically viable candidates and, of those, which NOx reduction technology should be installed?"

Without belaboring the discussion, among the candidate technologies were dry low NOx (DLN), selective non-catalytic reduction (SNCR), and three flavors of selective catalytic reduction flue gas treatment systems; *viz.,* high-temperature (HTSCR), low-temperature (LTSCR) and standard temperature (SCR).

Throughout the project from beginning to end, "CPDEP" principles and practice greatly contributed to the project's stunning success. The **C**hevron **P**roject **D**evelopment and **E**xecution **P**rocess is Chevron's common framework for asset or project development and execution. This five-phase model helps us to make more effective use of our resources; *viz.,* people, capital, and technology. CPDEP is a generic corporate project management and development process that can be adapted to meet the needs of specific operating company ("opco") lines of business.

A project that goes through a full life cycle results in the development and delivery of a product. The product that is delivered could be something like a modernized refinery, a dismantled facility, a network, or an application, depending on an opco's line of business. At Chevron Eastridge, the "SCR retrofit" was hardly limited to that most visible element of the work. It included a complete modernization of the cogeneration facility including turbine controls, displays and integration. In addition to DA and CPDEP, among the other corporate development and execution tools that directly contributed not only to project clarity but also to substantial cost reductions were "PEP" (Project Execution Plan), "FEL" (Front End Loading) and "IPA" (Independent Project Analysis).

The journey from dreams to reality is reflected in the perception of cost to achieve the desired result. The "reduction" of the perceived cost, largely owing to the application of management tools at each stage of development of the project, is striking:

- $14-million Original Estimate – Initial DA
- $26-million - 3rd Party Engineering Estimate (Oops***!***)
- $14-million – In-house Project Resources Check Estimate
- $8-million DA / CPDEP / PEP
- $6-million CPDEP / PEP / FEL / IPA
- $4-million CPDEP / PEP / FEL
- $3.25-million AFE ("**A**uthorization **F**or **E**xpenditure," the Corporate-management blessed "Thou Shalt Not Exceed" number***!***)

Also, from the point of view of the fiduciary responsibility of the project proponents to conserve the stockholder assets (*viz.,* capital dollars***!***), it didn't hurt that the proponents were aggressive and hard-nosed in the lump-sum contracting process. This business-like approach produced not only an exemplary technical design but also an exceedingly competitive bid from the successful prime contractor,[2] both project attributes of which corporate management and public stockholders alike are particularly enamoured***!***

Facility Modernization

During the SCR retrofit, plant management took advantage of the opportunity to modernize the Eastridge Cogeneration Plant control system into a very powerful SCADA ("**S**upervisor **C**ontrol**A**utomated **D**ata **A**cquisition") system. Turbine controls, distributive control system (DCS) and continuous emissions monitoring systems (CEMS) alike were upgraded with the latest technology. Moreover, these individual systems were linked to a common network to facilitate gathering, exchanging and storing data. This allows operators and engineers to utilize not only current data but also historical data in event identification, performance and efficiency evaluations.

Lastly, an unexpected but welcome benefit emerged from this retrofit project. Maintenance for this facility had been developed around the timeframe to perform both mechanical and instrumentation work. By replacing the former analog systems in the turbine governor control and DCS system with digital equipment, the same people working together have reduced the overall maintenance downtime by a remarkable 50%. This includes the additional maintenance burden associated with the new SCR systems which operators, mechanics and managers alike are pleased to report is minimal***!***

Now that the project is behind us, the visiting executives who are unfamiliar with the project ask, "What did you do?" and the plant operators notice no change except perhaps that operation has gotten a little easier.

In short, that's the Chevron definition of a "good retrofit;" *viz.,* one that just rocks along doing its job and nobody really notices. That's just fine by us***!***

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[1] Together with TechnipUSA (then Kinetics Technology International), Chevron pioneered the introduction in the United States of low temperature SCR technology at its El Segundo Refinery.

[2] Peerless Manufacturing Company, Dallas, Texas