

Upgrade your furnace for clean fuels

Reliability and environmental issues were key goals for this revamp of an existing reforming unit

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To meet the demand for CARB III gasoline requirements, Chevron decided to revamp the continuous catalytic reforming (CCR) unit at its El Segundo, California, refinery location. The project team defined the primary drivers:

- **Capacity improvement.** The feedrate was increased by more than 20%.
- **Feedstock change.** The feed source for this new capacity would come from straight-run naphtha, hydrotreated coker naphtha and hydrocracker naphtha. All of the available naphtha would be consumed to produce 99.5 (octane) C₅+ reformate.
- **Environmental.** In anticipation of stricter environmental regulations, a target 5-ppmv NO_x outlet emission level was set.
- **Reliability.** The unit revamp was to target a five-year run between turnarounds.
- **Schedule.** The majority of the work would be done during the unit turnaround scheduled for a 28-day outage (later changed to 35 days).

In the initial phase of the project, the process licensor identified the major equipment bottlenecks—the most complex challenges were the CCR furnaces. Due to the complexity of the upgrade and schedule constraints, the Chevron project team selected a general contractor and appointed a furnace specialist for the detail engineering phase of the project.

Furnace overview. The unit was originally designed in 1968 as a Rheniforming unit. The box-type furnace consisting of three radiant cells provided heat for

three reactors (Fig. 1). The reactor charge heater (F-410) and No. 2 (F-430) and No. 3 (F-440) inter-heaters were contained in the three radiant cells. Heat from the flue gas exiting the three inter-heaters was recovered to produce 450-psig saturated steam in a common convection section located above the radiant cells. In 1994, under a license, the unit was converted to a CCR processing unit.

Furnace configuration. The conversion to CCR process added a fourth reactor, which in turn required installing a freestanding furnace with its own convection section. To accommodate the stacked reactor design and minimize system pressure loss, the furnace coil arrangement changed from bottom to top inlet and outlet with the burners being relocated from the floor (vertical upshot firing) to one end wall (horizontal firing).

Balanced draft. The original furnace operation was natural draft. For the 1994 upgrade, the total fuel efficiency of the furnaces was increased to 91.5% (lower heating value basis) by the addition of an air pre-heater (APH) and forced-draft (FD) and induced-draft (ID) fans (Fig. 2).

Emission control. The South Coast Air Quality Management District (SCAQMD) Rule 1109 was in effect in 1994. This necessitated installing a selective catalytic reduction (SCR) unit to lower the flue gas NO_x emissions from the stack. The boiler feedwater (BFW) pre-heat coil in the original convection section was eliminated to raise the flue gas temperature to the desired range for the SCR unit (approximately 625–650°F). Accordingly, the unit was located upstream of the air pre-heater, and flexibility was built into the design by allowing for a bypass of the unit.

The 2004 SCAQMD permit application also led to:

- New requirements for a stack ammonia analyzer continuous emission monitoring (CEM) system

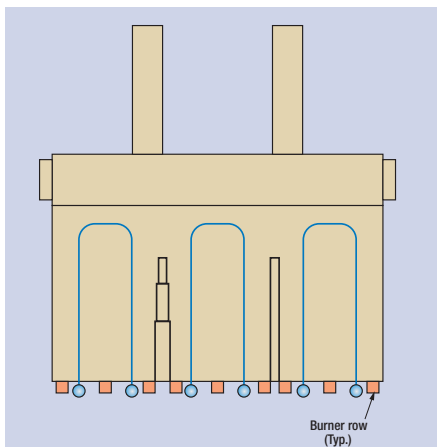


FIG. 1 Schematic of the original catalytic reforming unit.

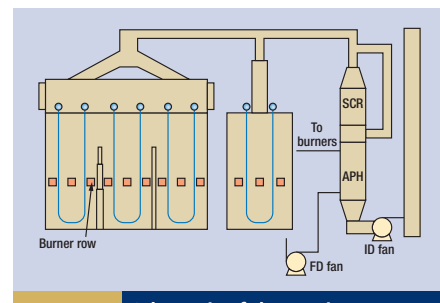


FIG. 2 Schematic of the continuous catalytic reforming unit as operating in 1994.

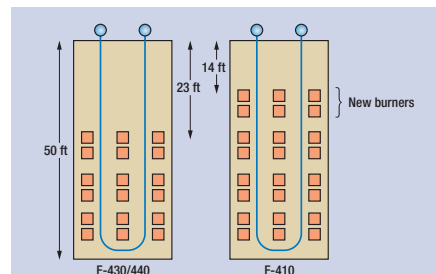


FIG. 3 Furnace schematic indicating burner locations.

TABLE 1. Furnace heat balance

	F-410	F-420	F-430	F-440
Pre-revamp				
Fired duty LHV, MMBtu/hr	86.9	129.8	86.1	60.2
Radiant absorbed duty, MMBtu/hr	58.7	88.1	58.2	42.9
Radiant heat flux, Btu/hr-ft ²	13,700	15,000	13,590	10,020
Bridge wall temp, °F	1,538	1,525	1,535	1,410
Normal peak tube skin temp, °F	1,150	1,115	1,070	1,085
Tube skin temp allowable limit, °F	1,175	1,175	1,175	1,175
Post-revamp, feed increase >20%				
Fired duty LHV, MMBtu/hr	153.7	173.5	107.0	76.6
Radiant absorbed duty, MMBtu/hr	92.2	108.8	69.1	52.8
Radiant heat flux, Btu/hr-ft ²	20,140	16,585	14,580	11,140
Bridge wall temp, °F	1,790	1,700	1,635	1,485
Normal peak tube skin temp, °F	1,151	1,124	1,124	1,098
Tube skin temp allowable limit, °F	1,175	1,175	1,175	1,175

- New furnace-fired duty limits
- New CO limit of 10 ppmvd.

For the 2004 revamp, the project goal was to increase the feedrate to the CCR by more than 20% at 99.5 octane for a full five-year run. During this upgrade, several changes were made to the furnace but changes to the compressor, reactor or regeneration section changes were avoided. From the furnace design standpoint, this was a significant change in capacity. Therefore, a detailed review was done to identify the critical process and mechanical details that were most at risk with respect to achieving the required capacity and five-year run.

Process review. A thermal model of the current furnace operation was developed after which the post-revamp case was simulated using the licensor's data. The model results identified several areas as potential limitations: heat flux, burner heat release, the F-410/430/440 convection section performance, SCR catalyst, APH recovery, and forced and induced draft capacity as shown in Table 1.

Mechanical review. With the higher expected flue-gas operating temperatures, a detailed review of the heater internals identified the shield section tube supports on the F-420 (Inter-heater #1) were inadequate to accommodate the increase in bridge-wall temperature. The 1994 re-vamp had upgraded the firebox refractory to ceramic fiber modules. Thus, the furnace skin temperatures were determined to be still within allowable limits.

Furnace upgrade options. During the initial process and mechanical review of the post-revamp operation, several furnace upgrade options were analyzed for economic and technical viability. Among those considered were:

New furnace. From cost and schedule considerations, as well as limited plot space availability, a new furnace was not a realistic option. Instead, the radiant heat-transfer surface area was increased to the maximum extent practical by optimizing tube size and spacing consistent with the allowable pressure drops and calculated maximum tube skin temperature of 1,175°F (Table 2).

Tube metallurgy. To accommodate the higher heat flux and potentially higher tube skin temperatures over the five-year run, it was decided to upgrade the nine chrome radiant tube metallurgy.

Burner consideration. It was determined that, for three of the

TABLE 2. Radiant heat transfer area

Radiant heat transfer area, ft ²	F-410	F-420	F-430	F-440
Pre-revamp	4282	5876	4282	4282
Post revamp	4578	6559	4739	4739

TABLE 3. SCR inlet deviations

Parameter	Target	Deviation	
		w/o vanes & plate	w/vanes & plate
Temperature, °F	±25	±17	±9
Velocity, %	±15	±23	±7
Ammonia, %	±10	±14	±6

cells (F-420, 430 and 440), the incremental increase in heat release, while large (>25%), could be accommodated with a burner retrofit and still meet industry standards with respect to burner-to-tube clearances. For the charge heater, F-410, however, the change in heat release was too large (~77%) and it was decided to add six burners to that cell, thereby enabling the new burners to be duplicated and limiting the retrofit of the existing burners to internals only, while achieving NO_x emissions lower than the 1994 revamp (Fig. 3).

Convection section. During the simulation phase, it became apparent that the common convection section above the F-410/430/440 cells was severely fouled as evidenced by the high exit flue gas temperature. It was concluded that, for the revamp conditions, the flue gas temperature would be potentially high enough to damage the SCR catalyst (> 875°F). Although cleaning the tubes was possible, it was considered high-risk as the convection section coils were from the original 1968 design and finned. The most cost-effective solution was replacing the entire convection section to ensure that the flue gas temperature to the SCR unit was not excessive and could achieve a five-year run.

Refractory coating. To protect the existing ceramic fiber insulation and improve the uniformity of re-radiation from the walls, the project team recommended applying ceramic coating to the radiant heater insulation.

CFD modeling. For the post-revamp operation, computational fluid dynamic (CFD) modeling was undertaken to validate two critical components of the combustion air and flue gas duct systems, both of which ultimately would effect emissions:

- The air distribution to the burners
- The flue gas distribution to the SCR unit.

The combustion air distribution to the individual burners in each cell was deemed acceptable. Duct modification was not necessary except for the F-410 cell where additional burners were being added and F-440 where the duct was enlarged to lower the air velocity and improve the distribution. The flue gas distribution to the SCR unit was improved by the inclusion of turning vanes and a 75% open-area perforated plate upstream of the catalyst bed (as shown in Fig. 4).

SCR catalyst. The latest generation of "medium" temperature catalyst technology was selected to meet the 5-ppmvd outlet NO_x limit.

Air pre-heater. With input from Chevron operations, the combustion air pre-heater was refurbished to address the following issues:

- **Capacity.** An additional hot and cold block module was incorporated into the design to allow for the increased duty requirements as well as to keep the total pressure loss through the system at an acceptable level.
- **Fouling.** Air pre-heater fouling on the existing unit was a

Continued

major concern for plant operations. The presence of fouling was determined to be from two sources: deposition of ammonia salts emanating from the reaction of excess ammonia from the SCR unit with sulfur oxides present in the flue gas. This led to increased pressure drop over time and ultimately limited the induced draft fan operation. The salts are soluble and an improved "online" water-wash system was proposed.

The other fouling was corrosion of the cold-end elements due to sulfuric acid condensation. This led to leakage of the combustion air to the flue gas and further contributed to the ID fan limitations over time. Based on a calculated acid dew point of 233°F, the minimum metal temperature (flue gas side) required had to be 258°F.

The project team recommendation here was to provide a steam APH upstream of the main APH to pre-heat the incoming air to 125°F and upgrade the cold-end elements with new ribbed-plate technology (known as cold-end insulator design), which promotes a more even profile for the cold-end metal temperatures (Fig. 5).

Fan consideration. The capacity increase in flow from the FD and ID draft fans was ~42%, sufficient to warrant replacement as other options such as wheel change or speed change were not viable. However, in the final analysis, it was possible to exchange the existing motors on the ID fan with the FD fan motors, resulting in cost savings for the project.

Project timeline. The project was driven by the plant turnaround date, which demanded a schedule that encompassed analysis, engineering design, procurement, fabrication and installation. The furnace modifications were initiated in September 2003 with turnaround work completed during October 2004 (Fig. 6). Due to market conditions, the critical path was the delivery and fabrication of the high alloy radiant tubes and the fabrication of the convection section modules.

Construction challenges. For the radiant cells, demolition of the existing tubular assemblies released the radiant sections for scaffolding to enable refractory work and installation of the additional burners to cell F-410 (Fig. 3). Ceramic coating was done after all tube, burner and refractory work was completed and cleaned up.

The new radiant coils posed transportation and construction challenges to the project team due to size and limited plot availability. Each cell has

multiple passes in an arbor configuration, which connect to a 30-in. inlet and outlet manifold (Fig. 2). The fully assembled arbors could not be shipped as one piece, which would have been ideal for field installation. Instead, for cells F-410, 430 and 440, each manifold was pre-fabricated in three sections and supplied to the field with radiant tubes attached which posed no problem both in transportation to the refinery and handling once there.

For the F-420 cell, which was the largest of the four cells, the manifolds were shipped in four sections. The final manifold assembly involved lifting each of the sections and installing them one by one in each cell and then welding them together. This approach dramatically reduced the field welding requirements during the turnaround.

Convection section. The common convection section serving cells F-410/430 and 440 is located 60 ft above grade atop the fireboxes but offset. It is approximately 6.5 ft high by 10.5 ft wide and 67 ft long. Due to this location, the convection section replacement work was carried out sequentially rather than concurrently with the radiant cell work. To mitigate schedule impact of this, it was decided that the convection section would be shipped fully modular-ready for installation.

The convection section was designed and shipped as two modules, each weighing 100,000 lbs. The convection modules were shop-fabricated including sidewalls, refractory, intermediate and end-tube sheets, tubes, return bends and header boxes installed.

Module erection. Once at site, the modules were stacked and welded together for installation as a single 200,000-lb lift. Hydro test was done prior to final installation. Following the shutdown, the existing convection section was demolished. The external sidewalls were then reinforced to sustain the structural integrity necessary to take the convection load during the installation. The unique feature here was that the lower ducts and the breech section were left in place while the new convection module was "slid" in place.

To facilitate the revamp, a roller system was used to allow installation from one end with

two cranes providing the lift. The two cranes were positioned and rigged to lift the convection module to engage one end onto the roller system. Using "come-alongs," the convection module was pulled into the cavity of the old convection section with gradual load transference from one crane onto the structure.

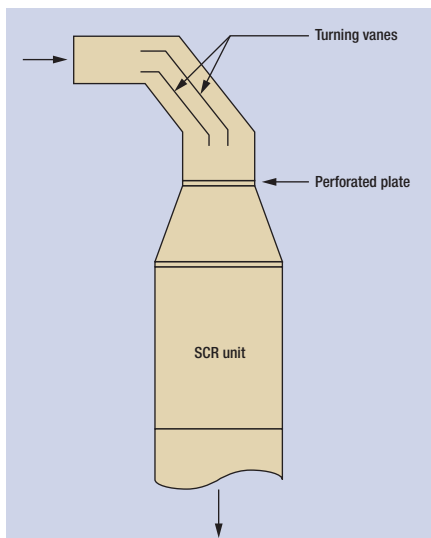


FIG. 4 SCR duct configuration.

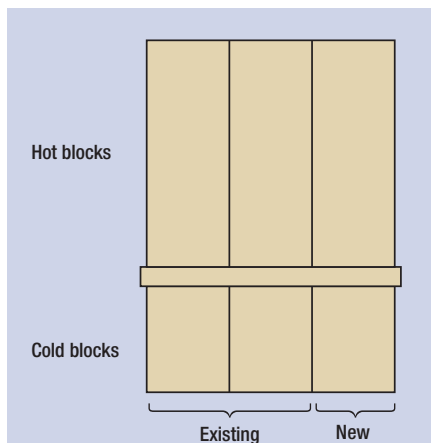


FIG. 5 APH schematic. New rib technology applied on the cold blocks.

Project milestones:

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project kick-off	█													
Engineering and design	█	█	█	█	█	█	█	█	█	█	█	█	█	
High alloy radiant tubes supply				█	█	█	█	█	█	█	█	█	█	
Radiant tube/manifold fabrication									█	█	█	█	█	█
SCR catalyst supply							█	█	█	█	█	█	█	
Convection section fabrication									█	█	█	█	█	█
Turn-around														█

FIG. 6 Furnace upgrade timeline. Furnace modification began in 2003 with the turnaround work completed during October 2004.



FIG. 7 The catalytic reformer before the revamp.



FIG. 8 The Chevron El Segundo catalytic reformer after furnace upgrades.

Once the module was in the final position, the new frame was bolted into place to the existing reinforced sidewalls and the load transferred to the structure.

Goals. In conclusion, the following goals set out by the project team were met:

- **Capacity improvement.** Feedrates exceeded design capacity at 99.5 (octane) C₅₊ reformat. Currently, the unit has achieved design processing capacity without exceeding the design furnace limits.

- **Environmental.** NO_x emissions are below the target of 5 ppmvd.

- **Schedule.** Modifications were scheduled for a 35-day stream-to-stream turnaround with 28 maintenance days. It actually took 31 maintenance days. However, the project was still rated 0.48 on construction schedule and 0.90 on a cost-effectiveness index from Independent Project Analysis. **HP**



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