FCC main fractionator revamps

Structured packing can influence unit pressure profiles and increase capacity

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Structured packing use in fluid catalytic cracker (FCC) main fractionators significantly impacts unit pressure profile. Unit pressure balance links the FCC main fractionator, reactor, regenerator, air compressor and wet gas compressor (Fig. 1). Many FCC units have capacity and/or conversion limits set by the wet gas compressor capacity or the air blower. A typical main fractionator has approximately 5 psi (0.35 kg/cm^2) pressure drop, while a packed fractionator has a 1.0 psi (0.07 kg/cm^2) pressure drop. This 4 psi (0.28 kg/cm^2) can be recovered and used to debottleneck the wet gas compressor or air blower. Unit pressure balance should be viewed as a design variable when evaluating FCC unit revamps. Depending upon limitations of the particular FCC unit, capacity increases of 12.5% to 22.5% have been achieved without modifications to major rotating equipment, by revamping FCC main fractionators with structured packing. An examination of three FCC main fractionator revamps show improvements to pressure profiles and unit capacity.

FCC units form an integral part of modern refineries' processing sequences for upgrading crude. Expanding these units often presents great difficulties and is expensive due to limitations on the main fractionator, wet gas compressor and air blower capacities. The packed main fractionator reduces pressure drop from the reactor outlet to the wet gas compressor. Reduced pressure drop benefits include:

• Increased suction pressure to the wet gas compressor to debottleneck the capacity and/or reduce wet gas compressor motor requirements

• Decreased discharge pressure from the air blower to debottleneck air blower capacity.

Additionally, structured packing allows for enhanced heat recovery options within the main fractionator. This can lead to additional benefits that include lower overhead system additional pressure drop. Actual benefits in any particular case depend upon balances derived from operating characteristics of the equipment in question.

Structured packing in FCC main fractionators. The first commercial use of structured packing in an FCC main fractionator was evaluated by Norm Lieberman[1] in 1983. Column capacity limited unit capacity, therefore, random packing was replaced with structured packing. Since that time, several units have been completely revamped with structured packing. These revamps have had varying
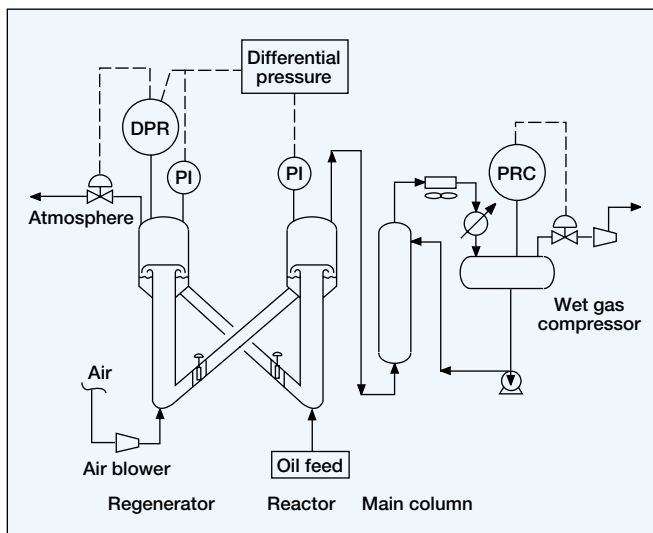

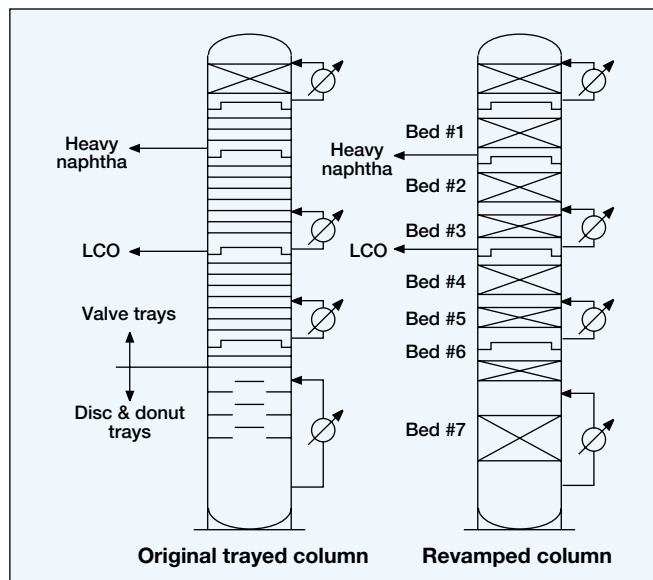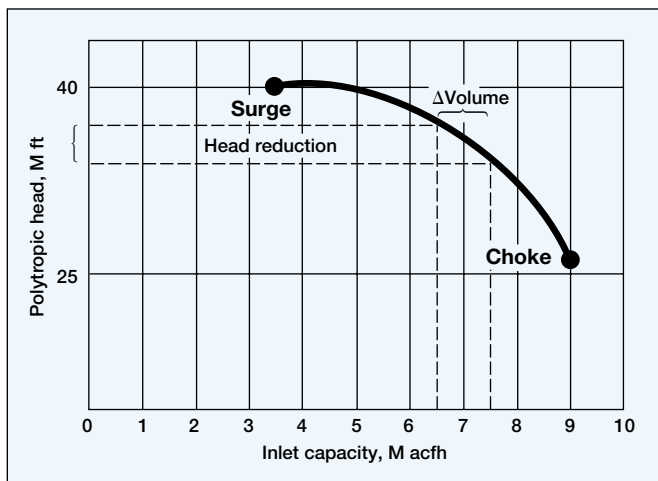**Fig. 1.** Simplified flow diagram of typical refinery FCC unit.

Fig. 2. Main fractionator column revamp with structured packing improves FCC pressure profile.

degrees of success. Problems in these columns have generally been associated with fundamental design errors in the liquid distributors. Flawed distributors resulted in poor fractionation bed performance. For this reason, packing in heavy oil fractionators has a very poor reputation with some refiners while others have used it repeatedly.

The inherent efficiency of structured packing in FCC main fractionators is very good. Therefore, care should be taken to separate packing benefits from problems associated with liquid distributor design. Separation on several revamped units is good. In at least one case, the apparent efficiency (measured in the plant) of structured packing
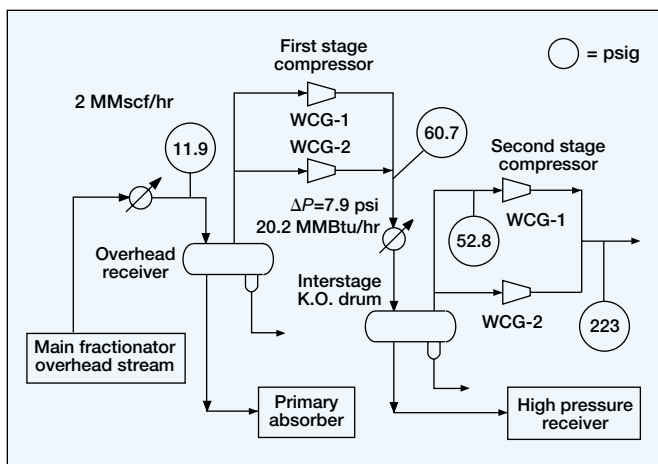
Fig. 3. Overhead system pressure profile and limited wet gas compressor volume—before replacing main fractionator trays with structured packing.
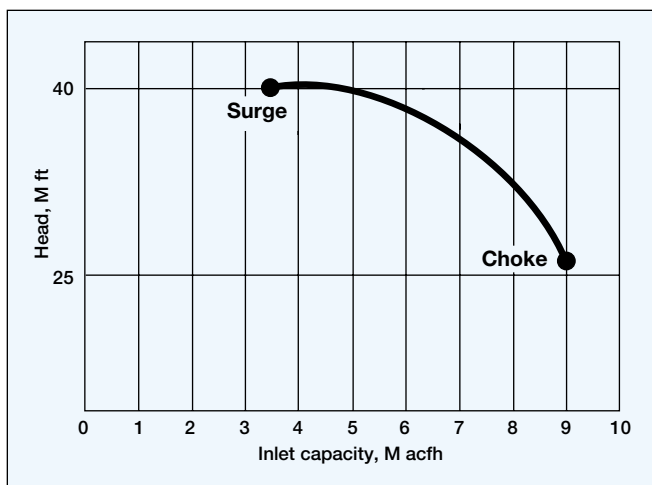

Fig. 4. Centrifugal compressor performance curve.

Fig. 5. Inlet volume increase associated with a compressor head reduction.

Fig. 6. Improved compressor system pressure profile, after revamping with structured packing.

improved from a 52-in. (132-cm) to a 24-in. (61-cm) height equivalent to a theoretical stage (HETP), by simply changing the distributors. On another main fractionator, 13 ft (3.96 m) ID and designed for 35,000 bpd (5,560 m^{3}pd), the design gasoline D-86 95 vol% point was 413°F (212°C), with the light cycle oil (LCO) product D-86 5 vol% point at 465°F (240°C). This is a 52°F (28°C) gap—evidence of a good packed bed performance given the reflux ratio in this section of the column. This column has consistently exceeded design separation performance from the initial revamp.
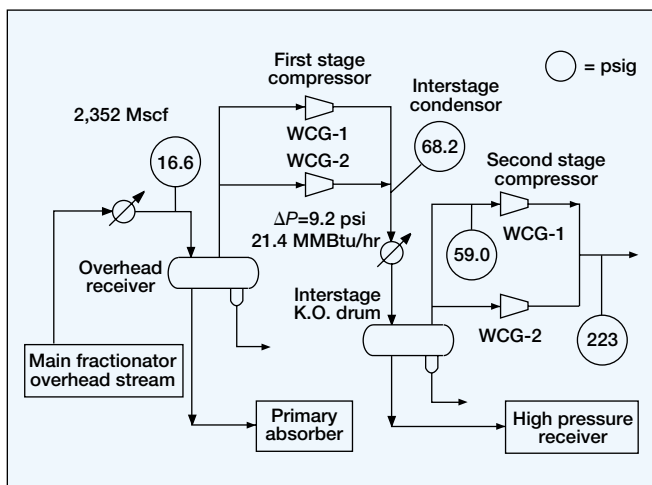
Packing impact on pressure profile. The separations issue aside, several refiners have successfully revamped the FCC main fractionator to debottleneck the wet gas compressor. Unit pressure profile changes have increased unit capacity by up to 20% without modifying the wet gas compressor or replacing the main air blower.

Operating history 1—wet gas compressor volume limit. The FCC main fractionator pressure profile impact on the wet gas compressor for a revamped unit is examined. Operating data for the wet gas compressor system before and after the revamp will be evaluated. Fig. 2 compares the main fractionator column with trays and after the revamp with structured packing.

The main fractionator was revamped with structured packing to reduce column pressure drop, raise suction pres-

sure to the compressor, and increase unit capacity. The unit has two parallel compressors with a common interstage condenser system and knockout drum (Fig. 3). A summary of the overhead system pressure profile (before revamp), which resulted in the wet gas compressor volume limit, is also described in Fig. 3. Operating performances for the compressor's first and second stages are shown in Figs. 7 to 10. The wet gas compressor was volume limited and this set the unit capacity of 80,000 bpd (12,720 m^{3}pd).

Compressor performance. A centrifugal compressor develops a certain head for any given inlet flowrate. It is important to understand that the performance curve is inlet capacity based on actual volume units. The gas density will effect the ability of the compressor to move a given mass of gas. A performance curve for a centrifugal compressor is represented by Fig. 4. Assuming the compressor is operating on a given point on its curve, then compressor capacity in mass units can be increased by decreasing polytropic head and/or increasing gas density. The inlet volume increase associated with a compressor head reduction is described graphically in Fig. 5. The equation:

$$H_{poly} = (1{,}545/MW)*[Z_{avg}T_1]/((N-1)/N)]*[(P_2/P_1)^{(N-1)/N}-1]$$

shows the calculation for polytropic head.

This equation shows that the polytropic head can be reduced by increasing suction pressure (P_1), decreasing inlet temperature (T_1) or decreasing discharge pressure
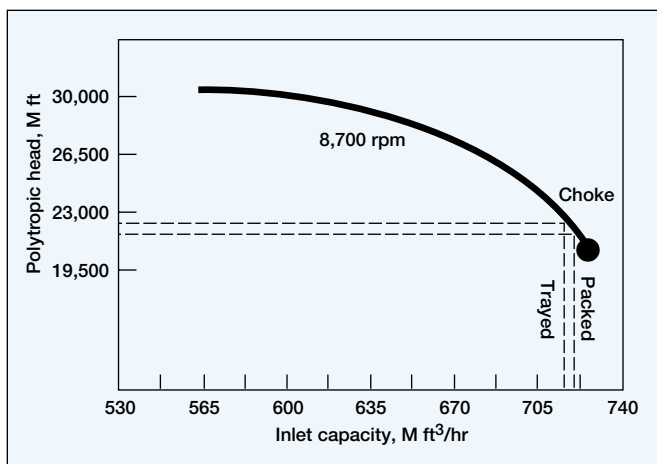
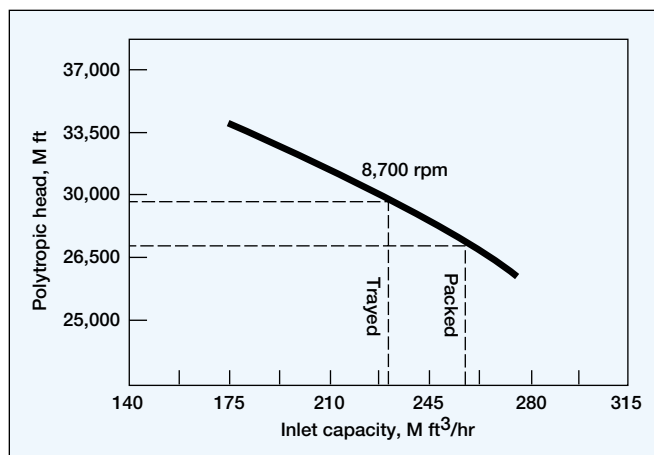**Fig. 7.** Wet gas compressor (WGC-1) performance—first stage.

Fig. 8. Wet gas compressor (WGC-1) performance—second stage.
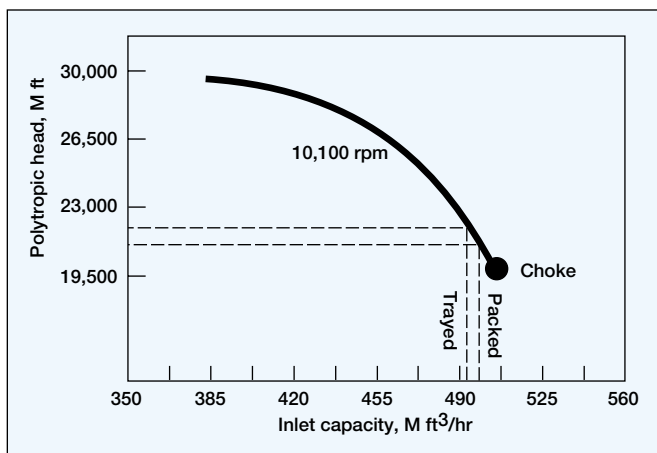

Fig. 9. Wet gas compressor (WGC-2) performance—first stage.
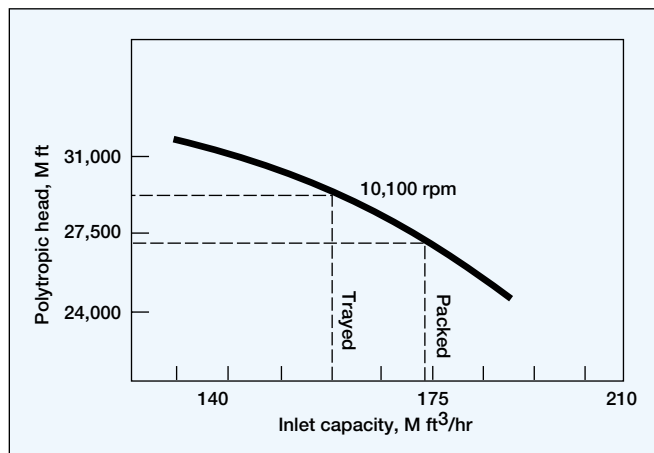

Fig. 10. Wet gas compressor (WGC-2) performance—second stage.

(P_2). Compressor discharge pressure is fixed by gas recovery unit pressure, and generally cannot be decreased without significant losses of C_3 molecules to fuel gas. Compressor molecular weight is generally fixed assuming a given reactor effluent composition. Attempting to increase main fractionator overhead molecular weight at a constant reactor effluent composition requires a hotter main fractionator overhead (to maintain the heavier material in the vapor). For most units, this is counterproductive. The increased volume due to increased condenser outlet temperature outweighs the benefit gained by the higher molecular weight.

This leaves increasing pressure to the wet gas compressor as the most attractive debottlenecking option. Gas density increases with an increased wet gas compressor suction pressure, permitting high mass flowrates at a constant inlet volume condition of the wet gas compressor. Assuming a fixed main fractionator inlet pressure, an increased wet gas compressor suction pressure requires a lower pressure drop across the main fractionator and/or a condenser system.

Column revamp. The column trays were replaced with structured packing. This reduced column pressure drop from 5.7 psi (0.40 kg/cm²) to 1.4 psi (0.10 kg/cm²). Compressor inlet pressure was increased by a corresponding amount. Suction pressure increases for any given compressor inlet has three positive effects on compressor and unit capacity:
- Lower polytropic head
- Higher gas density
- Lower wet gas volume per unit of feed.

Table 1. Wet gas compressor analysis

	Trayed column	Packed column
Gas capacity, MMscfh	2,002*	2,352*
Suction pressure, psig	11.9	16.6
Discharge pressure, psig	223	223
Compressor power, hp	7,175	7,926
Column ΔP, psi	5.7	1.4
Unit capacity, bpd	80,000	95,000

* Compressor volume limited

Reduced wet gas molecular weight resulting from higher pressure has a negative impact on compressor capacity, but this is very small. Wet gas hydrogen and methane content have the largest impact on molecular weight, and these are primarily a function of reactor operation, feed quality and catalyst management.

The improved compressor overhead system pressure profile, after the revamp, is shown in Fig. 6. Compressor suction pressure was increased from 11.9 psig (1.87 kg/cm²) to 16.6 psig (2.20 kg/cm²) with the packed main fractionator. Figs. 7 to 10 show the compressor performance comparison between trayed and packed main fractionators. Table 1 summarizes the unit capacity change associated with packing the main fractionator, with a unit feed gain of 22.5% at wet gas compressor suction volume limit. The actual impact in a particular case of pressure reduction is highly dependent on the compressor curve and the current operating point. On all centrifugal compressors the curve is much "flatter" near the surge line and becomes very "steep" toward stonewall. The wet
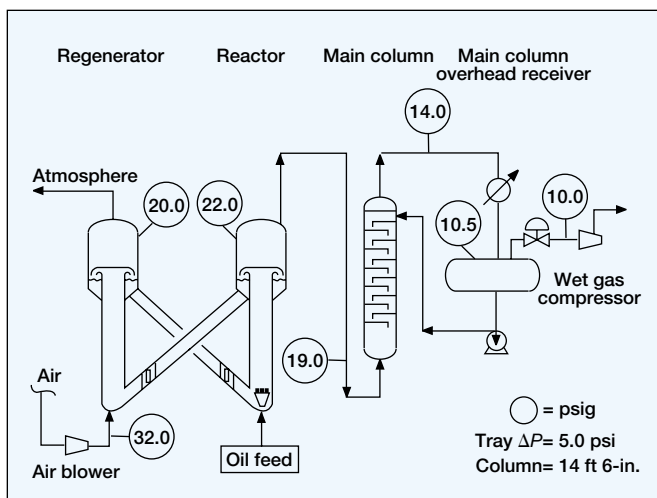
Fig. 11. Unit pressure profile (40,000 bpd) before revamping trayed main fractionator.
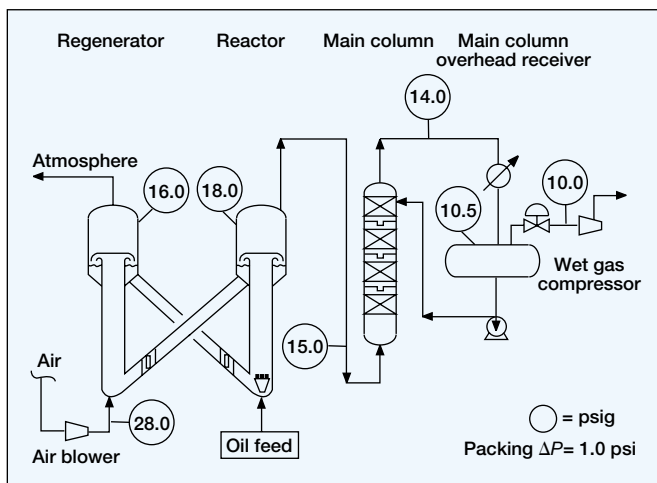

Fig. 12. Unit pressure profile (40,000 bpd) after revamping trayed main fractionator with structured packing.
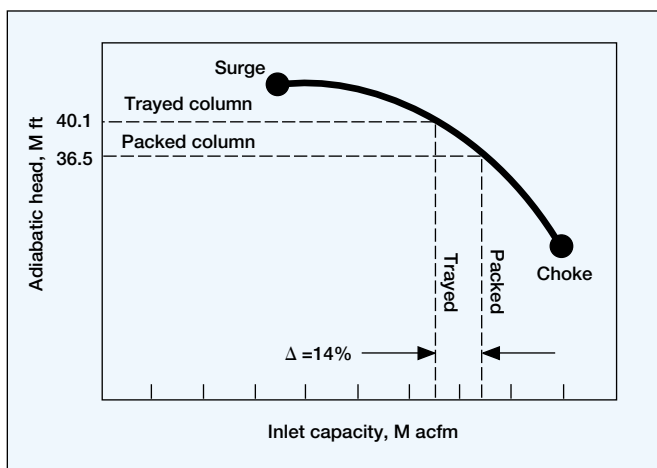

Fig. 13. Centrifugal air blower performance resulting from the two regenerator pressures before and after revamping—40,000 bpd FCC, complete combustion.

gas compressor in this case is operating near stonewall with trays, therefore the capacity advantage of increased suction pressure was minimized because of the compressor operating point.

Other equipment changes were required to increase capacity by this magnitude. But two of the most difficult items to expand, the main fractionator and wet gas compressor system, did not need to be replaced.

Table 2. Pressure profile summary—40,000 bpd		
	Trays	**Packing**
Wet gas compressor suction	10.0	10.0
Main fractionator top	14.0	14.0
Main fractionator bottom	19.0	15.0
Reactor	22.0	18.0
Regenerator	20.0	16.0
Air compressor outlet	32.0	28.0
Pressure, psig		

Operating history 2—air blower limitation. A 35,000-bpd (5,565-m³pd) unit was revamped to increase unit capacity to 40,000 bpd (6,360 m³pd). The 14-ft (4.27-m) ID main fractionator was a major bottleneck because existing column internals did not meet the required capacity. The revamped main fractionator required packing to meet new capacity requirements. Fig. 11 summarizes the unit pressure balance prior to revamp. Maintaining the same unit pressure profile would have resulted in an air deficiency of approximately 10% after revamp. The centrifugal air blower was volume limited, which limited incremental regenerator coke burning capacity. A new air blower or smaller parallel air blower would have been required to meet combustion air requirements. The existing wet gas compressor was adequately sized for the new 40,000 bpd (6,360 m³pd) feed rate.

In the first example, the pressure drop reduction in the main fractionator was used to raise wet gas compressor suction pressure. Referring to Fig. 1, it is the reactor-regenerator differential pressure that must be controlled within a relatively narrow +2 to −2 psi (+0.14 to −0.14 kg/cm²) regenerator-reactor range. When the wet gas compressor is limiting unit capacity, the regenerator and reactor pressures are held constant while the compressor suction drum pressure is increased.

In this case, the main fractionator was revamped with structured packing to attain the main fractionator capacity target. At the same time structured packing in the main fractionator reduced system pressure drop by 4 psi (0.28 kg/cm²). This 4 psi (0.28 kg/cm²) pressure drop reduction was used to lower reactor and regenerator pressures. Figs. 11 and 12 summarize the unit pressure profile before and after the revamp. Table 2 is a comparison of the pressure balance before and after the revamp. Fig. 13 shows the resulting compressor performance for the reduced regenerator pressures. The 4 psi regenerator pressure reduction increased the usable compressor capacity by 14% for this particular compressor.

On any operating unit, when either the air blower or wet gas compressor capacity is limiting unit capacity, reactor or regenerator pressures can be modified to maximize unit capacity. For main fractionator revamps, column pressure should be viewed as a variable within the upper and lower limits of trays vs. structured packing.

Operating history 3—wet gas compressor motor limitation. A 40,000-bpd (6,360-m³pd) unit was operating with a wet gas compressor motor limitation. Unit capacity was to be increased to 45,000 bpd (7,155 m³pd) and the compressor driver needed to be replaced. Main fractionator trays were limiting at 40,000 bpd (6,360 m³pd). The pressure drop from the reactor to the wet gas compressor consists of reactor effluent line, main fractionator, overhead condensing system and compressor suction control valve pressure drops (Fig. 1). The condensing systems can have pressure drops of up to 10 psi (0.70 kg/cm²) on some units. This particular refinery
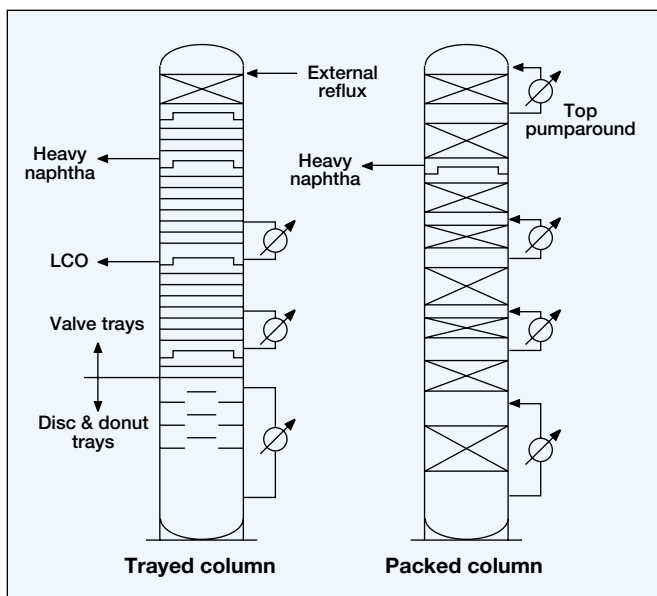
Fig. 14. Revamped main fractionator with new top pumparound.

Table 3. Main fractionator top pumparound

	No pump-around	Top pump-around
Charge rate, bpd	45,000	45,000
Top pressure, psig	14.0	14.0
Top temperature, °F	306	296
Condenser duty, MMBtu/hr	141.4	120.2
Condenser ΔP, psi	6.6	4.5
Outlet pressure, psi	7.4	9.5
Compressor power, hp	5,442	4,924
Receiver temperature, °F	114	107
Gas rate, acfh	+20	Base
Top pumparound duty, MMBtu/hr	0	28.7

Note: Exchanger surface area, 26,445 ft²
Cooling water rate, 4,535,000 lb/hr
Cooling water inlet temp, 86°F
Motor power, 5,000 hp

Fig. 15. Effect of top pumparound on FCC wet gas compressor—overhead system pressure and temperature profile with and without a top pumparound.

had several possible low temperature heat sinks in the form of cold gas oil charge preheat, demineralized water preheat and C_3 splitter reboiler heat. The compressor had a 5,000-hp (3,730-kW) motor that was operating near its amp limit at 40,000 bpd (6,360 m³pd).

The column needed structured packing in several sections to handle higher capacity. The original design had slurry, HCO and LCO pumparounds prior to revamp. Addition of a top pumparound (naphtha) increased the unit energy efficiency, recovering heat lost to the overhead condensing system water coolers. The new top pumparound was added without reducing fractionation efficiency between heavy and light cat naphthas. By adding a top pumparound, the overhead condenser load was decreased by 21.2 MMBtu/h. Pumparound draw temperature was approximately 360°F (182°C) in this case. The existing overhead system pressure drop was 2.1 psi lower with the top pumparound.The increased wet gas suction pressure dropped the compressor load below the limit of the compressor motor. This allowed for the expansion to 45,000 bpd (7,155 m³pd) of feed without replacement of the wet gas compressor motor.

The revamped column (Fig. 14) did not use fin-fans but used only water-cooled shell-and-tube exchangers. Fig. 15 shows the overhead system pressure and temperature profile for 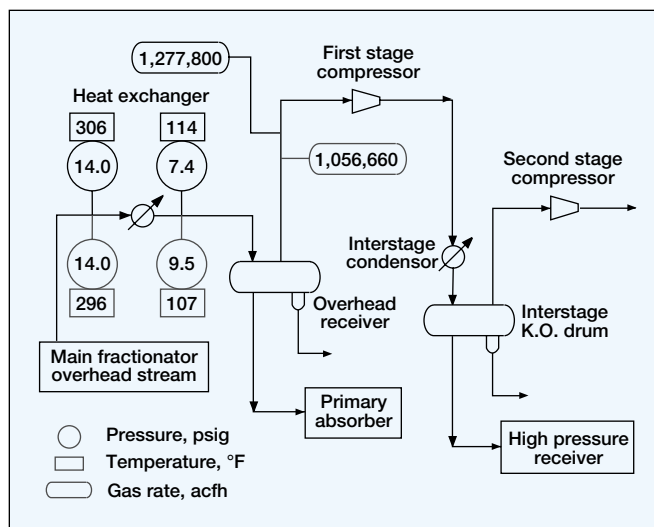the system with and without a top pumparound. Wet gas compressor gas rate (actual volume) is reduced by 20%. Effects of the top pumparound on the wet gas compressor are summarized in Table 3. Addition of a new top pumparound reduces compressor horsepower requirements by 10%.

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[3] Anon, *Engineering Data Book,* Tenth Edition, 1987, Vol. 1, Section 13, Eq. 13-27b, Gas Processors Suppliers Association, Tulsa, Okla.

The authors

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