Field Data, New Design Correct Faulty FCC Tower Revamp

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In 1987, Lyondell Petrochemical Co. revamped a fluid catalytic cracking unit (FCCU) main fractionator by replacing trays with structured packing. This revamp did not achieve its design objectives; therefore, a second revamp was performed in 1992. Packing large diameter main fractionators can increase unit capacity and decrease pressure drop while meeting fractionation objectives. However, a packed main fractionator revamp is less forgiving than a trayed column revamp and must take into consideration proper design and inspection procedures. Lyondell's experience illustrates the approach needed to have a successful structured packing revamp.

Background

The 79,000 b/d FCCU main fractionator at Lyondell Petrochemical Co.'s Houston refinery was first revamped from trays to structured packing in 1987 (Figure 1). The justification for the revamp was a capacity increase to 92,000 b/d. An ultimate capacity of 100,000 b/d was anticipated, at the same gasoline cutpoint as the trayed column, and at reduced column pressure drop. The revamp design gasoline D86 endpoint was 445°F.

Reactor-regenerator pressure balance is affected by main column pressure drop. (Figure 2) Before the revamp, unit capacity and conversion had been limited by low cat-to-oil ratio. Reducing pressure drop would allow lower reactor operating pressure, which permits higher catalyst circulation and increased conversion. The revamped unit pressure-balance also permitted lower regenerator pressure.[1,2] The revamp included a new regenerator air grid design that would generate higher pressure drop; therefore, the regenerator pressure had to be lowered to maintain the air blower discharge pressure at the required level to meet the regenerator air requirements.

After the revamp, at 92,000 b/d charge rate, the gasoline true boiling point (TBP) endpoint was consistently 550°F or higher. The endpoint did not change with increased fractionator reflux or decreased unit feed rate. High gasoline endpoint resulted in 7,000 b/d of heavy gasoline being blended to the middle distillate pool and 2,400 b/d gasoline lost to LCO product. Several modifications to the packed column internals did not improve gasoline quality. The column internals eventually were modified by a second revamp. This revamp met the 92,000 b/d capacity, but also the design pressure drop and fractionation. Packed main column internals must be properly designed, installed, and inspected before start-up to ensure good performance. Many packed columns have failed because of poor design practices or faulty installation.

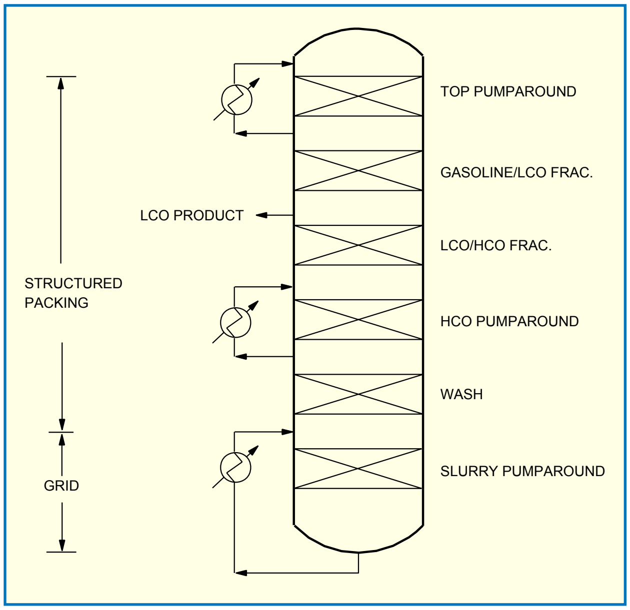

Figure 1 *Initial Column Revamp*

Problem Definition

The project justification was increased charge rate, higher gasoline production, and lower pressure drop. The main fractionator raw gasoline (liquid product from overhead receiver) had a high endpoint and the light cycle oil (LCO) product contained 2,400 b/d of recoverable gasoline. The gas plant fractionates full range gasoline into light, middle (heart-cut), and heavy gasoline prior to blending or reprocessing (Figure 3).

In addition to high gasoline endpoint, the LCO product consistently had a TBP 20 vol % point of 430°F or less. Gasoline losses included 7,000 b/d of heavy gasoline, which had to be blended to the middle distillate pool year-round, and 2,400 b/d gasoline loss to LCO product. The remainder of the 550°F endpoint heavy gasoline could be blended to the refinery gasoline pool because of the masking effects of the light refinery gasoline blending components.

The approximate FCC gasoline material balance after the revamp was:

- Light gasoline (gasoline splitter): 17,600 b/d
- Light gasoline (cat. naphtha fractionator): 4,800 b/d
- FCC gasoline splitter bottoms: 6,000 b/d
- Heart-cut: 9,950 b/d
- Heavy gasoline: 12,000 b/d
- Total FCC gasoline: 50,350 b/d

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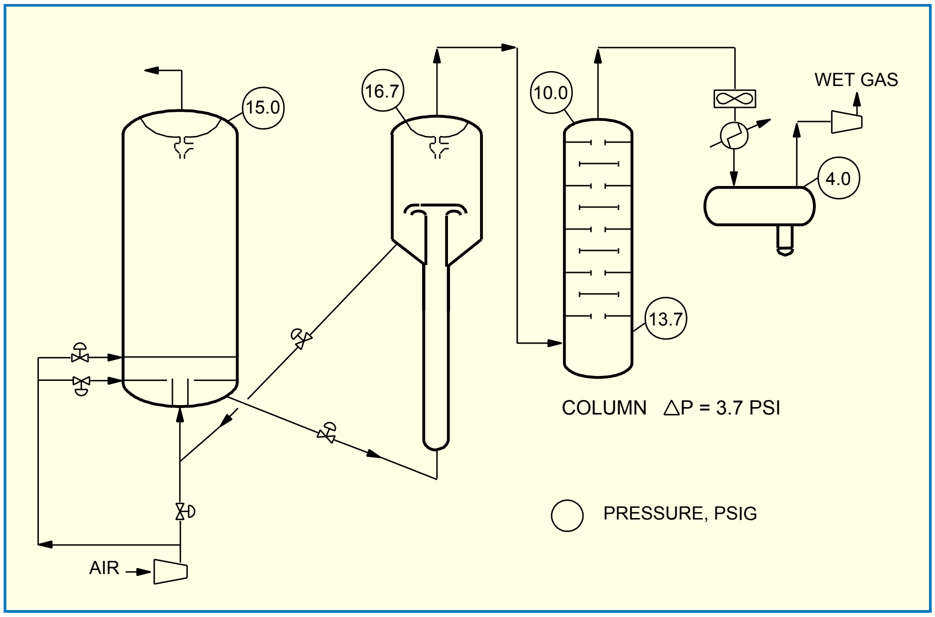

Figure 2 *FCC Pressure Balance (Trayed Column)*

Field Troubleshooting

Field troubleshooting was performed after initial attempts to correct the problem failed. Several field observations were made:

- The column overhead vapor temperature did not respond to increased reflux. At times, the overhead temperature actually increased with higher reflux.
- The gasoline endpoint and the front end of the LCO did not change materially with large reflux rate changes.
- The fractionation between the unstabilized gasoline and the LCO product was the same at 60,000 b/d or 92,000 b/d feed rate. At 60,000 b/d, large reflux rate changes had little or no effect on fractionation.
- The measured column pressure drop was near the design value. The individual bed pressure drops could not be measured because no instrument taps were installed (and low pressure drop is difficult to measure accurately.)

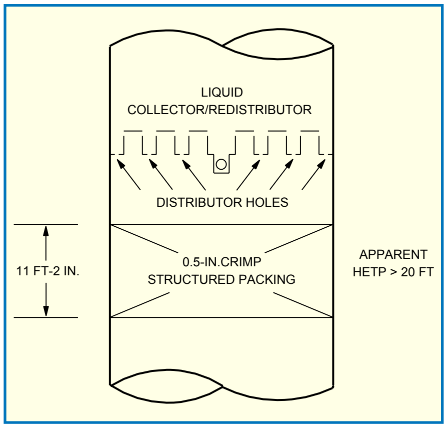

Figure 4 *Gasoline/LCO Fractionation*

Field testing showed poor fractionation throughout the column. Poor initial distribution and/or little or no remixing of internal liquid often cause poor fractionation. Poor liquid distribution causes variations in liquid/vapor ratios across the tower cross sectional area, which result in composition gradients. Figure 4 is a schematic of the gasoline/LCO fractionation section. This bed had approximately 0.5 theoretical stages, or an apparent height equivalent of a theoretical plate (HETP) of greater than 20 feet. Refinery main fractionator beds are short (3-8 theoretical stages) and the columns are typically large diameter. If one cross-section of the bed has an L/V ratio much lower than another section, the result will be high endpoint material leaving the low L/V section of the column. Lyondell concluded that there was poor liquid distribution and the consensus was that structured packing does not work in large diameter FCC main fractionators. A test run was planned to gather additional field data.

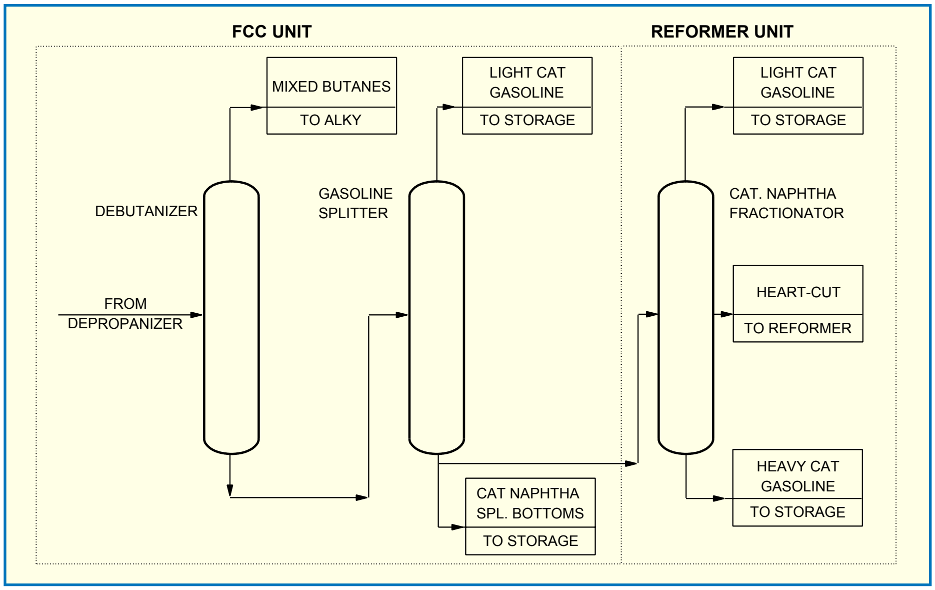

Figure 3 *FCC Gasoline Fractionation System*

Initial Revamp Justification

The original column design used trays, which limited FCC feed to 79,000 b/d (Figure 5). The measured trayed column pressure drop was 3.7 psi. At 79,000 b/d, 75% conversion, and test run heat and material balance conditions, the calculated pressure drop using the column internal loadings was 3.6 psi. The stated revamp objective was a 15% increase in feed rate while maintaining fractionation comparable or better than the trayed column. Minimizing column pressure drop consistent with these stated objectives had product conversion benefits. Reduced pressure drop allowed adjustments in the reactor/regenerator pressure profile. These adjustments enabled Lyondell to increase the catalyst-to-oil ratio with a corresponding increase in unit conversion and selectivity. The regenerator pressure was lowered, permitting higher air grid pressure drop without reducing air blower capacity.

Table 1 shows the raw gasoline and LCO product distillations during a test run of the trayed column. The top circulating reflux operated at about 126 MMBtu/hr heat removal, which equates to about 58,000 b/d of internal reflux. Table 2 shows the calculated percent flood and observed fractionation section efficiencies. The tower performance had approximately three theoretical stages between

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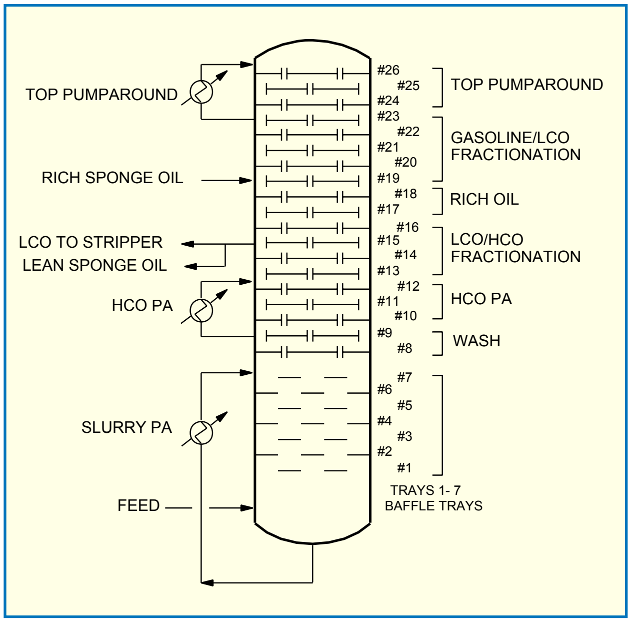

Figure 5 *Trayed Columns, Capacity 79,000 B/D*

Trayed Column Distillation Curves

	D86 Temperature, °F	
	Raw Gasoline	**LCO Product**
IBP	--	265
5	--	392
10	92	415
30	178	492
50	255	545
70	331	604
90	399	681
95	416	715
EP	442	736

5-95 vol% overlap, 24°F.

Table 1

Trayed Column Capacity/Efficiency

Section	% Flood	NTS*
Top pumparound	100	--
Gasoline/LCO	88	3
LCO/HCO	80	2
HCO Pumparound	91	--
Wash	70	1
Slurry	71	--

*Calculated number of theoretical stages

Table 2

the top pumparound and the LCO product draw stream. The trayed fractionator was flooding in one section, although the exact section could not be determined. Lyondell conducted a plant test to determine whether the flooded section could be isolated. The top pumparound had the highest calculated percent flood. It was postulated that if this section of the column was flooding, the fractionation could be improved by reducing the loading in the raw gasoline/LCO fractionation section.

Field testing was done to determine where the column was flooding. The heat balance was adjusted to lower the load on the top section of the column. Approximately 17 MMBtu/hr were shifted from the top pumparound to a previously shutdown LCO pumparound system. The fractionation became worse, which showed that the gasoline/LCO section was not flooding. Two theories prevailed. The first assumed the slurry pumparound baffle trays were flooding, resulting in massive entrainment of liquid to the wash zone trays. The second theory was that wash zone trays 8 - 9 were flooded by high vapor rates caused by reduced slurry pumparound heat removal. The symptoms of the flooding were rapid loss of column bottoms level and rapid buildup of pressure drop in trays 9-17, where a differential pressure recorder was installed.

Increasing slurry pumparound heat removal and raising column pressure eliminated flooding. Increasing the main fractionator pressure was not a reasonable control method because of its adverse effect on the pressure balance. The operators monitored the tray pressure drop and maintained the slurry pumparound duty at about 200 MMBtu/hr to avoid flooding. The column was operated with maximum slurry pumparound duty consistent with the slurry product gravity specification. Heavy cycle oil (HCO) product was sent to fuel oil blending to control the slurry product to less than -1.0 API gravity. Slurry is sold as carbon black feedstock. If the slurry pumparound heat removal was too high, it was not possible to meet the slurry product gravity specification because too much light material was condensed.

The first revamp was done to increase capacity and raise conversion. Lyondell decided to replace the trays with structured packing. The baffle trays were replaced with grid and the remainder of the internals with structured packing. The packed column hydraulic design was consistent with 100,000 b/d fresh feed at 75% conversion, although the unit capacity was limited to 92,000 b/d because of environmental permit limitations. A new wet flue gas scrubber planned for 1994 would allow operation at as much as 102,000 b/d. Table 3 summarizes the fractionation bed depth and design packing performance. The column has two pumparound side draws and one product side draw (Figure 6).

A combined liquid collector/redistributor was selected to decrease the height required for pumparound/product draws, which allowed maximum packed bed depth. The design column pressure drop was 0.8 psi. The packed column started up in early 1987.

Revamp Column Performance

The design performance objective was improved fractionation in all zones. When the column started up, some of the initial distillation data showed a gasoline splitter bottoms product endpoint as high as 575°F, with typical values as shown in Table 4. The FCC gas plant initially separates the full range gasoline in a gasoline splitter column, producing light gasoline overhead and a bottom product. Part of the bottom product is routed to a heart-cut splitter in the reformer and the remainder is sent to storage. The heart-cut splitter separates the heavy gasoline into light, heart-cut and heavy gasoline streams. The light and heavy cuts are refinery gasoline blendstocks and the heart-cut stream is reformer feedstock.

Original Design Separation Efficiency

Fractionation Zone	Packing	Bed Height, in.	Design HETP, in.	NTS*
Gasoline/LCO	1/2-in. crimp	134	21	6.4
LCO/HCO	1/2-in. crimp	62	21	3.0
HCO/Slurry	2-in. crimp	42	42	1.0

* Number of theoretical stages

Table 3

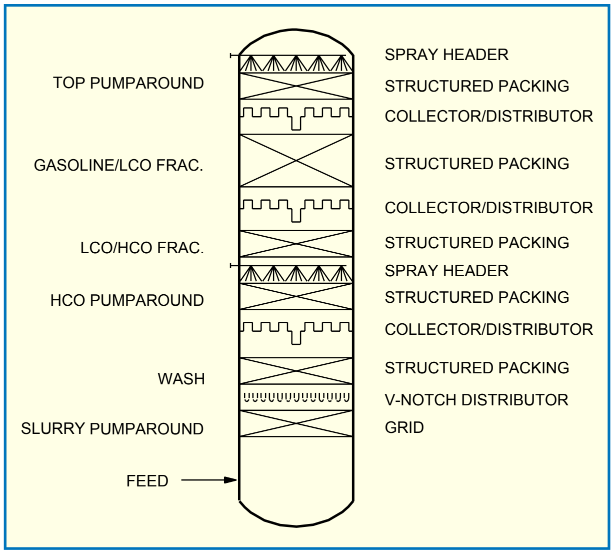

Figure 6 *Original Packed-Column Internals*

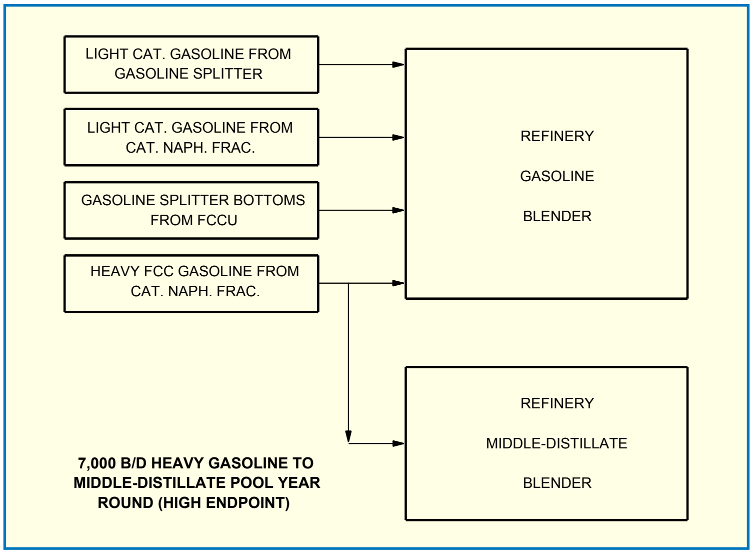

Figure 7 *Blending Problems-High Endpoint FCC Gasoline*

Heavy Gasoline Distillation (Initial Revamp)

Vol%	Temperature, °F
90	420
95	460
97	490
99	550

Table 4

A test run was conducted on Oct. 7, 1987 at 93,700 b/d charge. Table 5 shows the raw gasoline and LCO product D86 distillations.

The packed main column was producing high endpoint gasoline and the LCO product contained a large amount of gasoline. Poor fractionation caused 2,400 b/d of gasoline loss directly to LCO product. However, the main problem was the high endpoint gasoline. Of the total FCC gasoline production, about 7,000 b/d had to be blended to the refinery middle distillate pool year-round (Figure 7). During winter months, the refinery operated in maximum middle distillate mode, and the 7,000 b/d was typically needed for middle distillate production. Therefore, during gasoline season, 14% (excluding gasoline lost to LCO) of the FCC gasoline production was lost to the middle distillate pool, which had a major impact on refinery economics. The heaviest portion of the FCC gasoline has a low RVP relative to average FCC gasoline. The impact on the total refinery gasoline pool is thus greater than the volume loss of 7,000 b/d. The two possible solutions were to replace the packing with trays or fix the packed column.

Raw Gasoline/LCO Distillation (Initial Revamp)

Raw Gasoline		LCO	
Vol%	Temp., °F	Vol%	Temp., °F
70	316	IBP	282
90	380	5	389
95	408	10	413
97	481	20	449
EP	540	30	485

Table 5

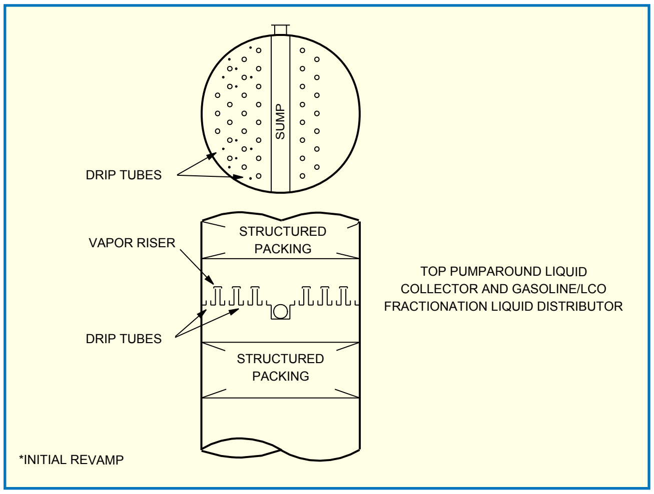

Figure 8 *Blending Problems-High Endpoint FCC Gasoline*

Troubleshooting

Packed columns do not fractionate where there is poor liquid distribution, flooding, and/or poor vapor distribution. The initial revamp used a combined collector/distributor to maximize packing bed depth. Figure 8 shows the combined top pumparound liquid collector and gasoline fractionation section distributor. The top pumparound design rate was about 6,000 gpm, while the design internal liquid rate to the fractionation section was about 3,500 gpm. A combined pumparound collector and liquid redistributor device has never been used successfully in large diameter fractionators. To illustrate, Table 6 summarizes the observed HETPs of the fractionating beds.

Theoretically, the operation of the combined collector/distributor will cause poor liquid distribution. Gathering field data to prove that liquid distribution was poor was difficult because the column had few temperature measurements. The column overhead and top pumparound draw temperatures before the revamp were available. Table 7 shows the recorded temper-

Initial Revamp Fractionation Performance

Zone	Actual NTS	Actual HETP, ft.
Gasoline/LCO	<1	>10
LCO/HCO	0	>10
HCO/Slurry	0	>10

Table 6

Temperature Comparison, Trays vs. Packing

	Trays	Packing (Initial Revamp)
Top Temperature	284	276
Top Pumparound Draw Temperature	348	380
Raw Gasoline D86 Distillation, Vol%		
90	399	393
95	416	424
100	442	540

Table 7

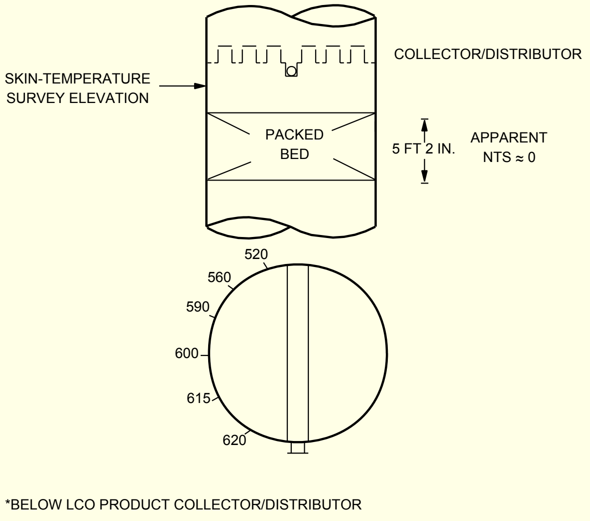

Figure 10 *Skin Temperature Above LCO Draw*

ature at about the same top column pressure before and after the revamp.

After the revamp, the top pumparound draw temperature was much higher, indicating high endpoint material at this elevation in the column. The pumparound draw temperature is its bubblepoint; therefore, the higher draw temperature implies high endpoint. Previous distillation analyses of the top pumparound draw were not available. The column had no thermowells. However, vessel skin temperatures could be measured with a portable thermocouple to infer column internal temperatures. Skin temperatures can be calibrated against actual internal temperatures by measuring skin temperatures near a column thermowell. If skin temperatures are measured radially either above or below a packed bed in the vapor space, the magnitude of maldistribution can be inferred from the temperature differences of the radial measurements.

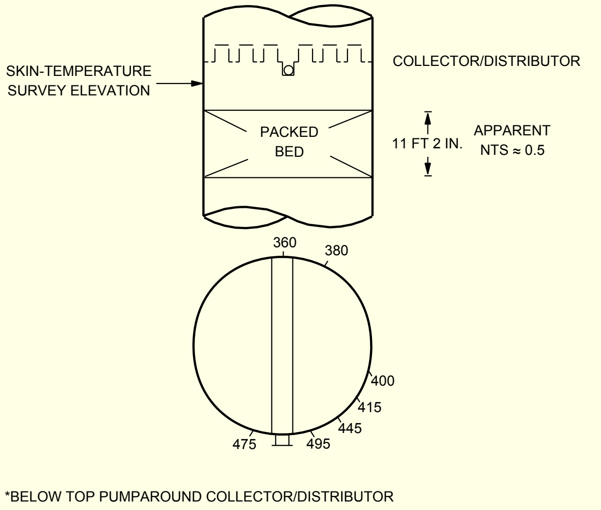

Figure 9 *Radial Skin-Temperature Below Top Collector*

Figure 9 shows a radial survey taken below the top collector/redistributor. The temperature varied from 495°F near the draw nozzle to 360°F directly opposite the pumparound draw nozzle. Figure 10 is a radial skin temperature survey taken above the LCO product draw tray. The skin temperature data showed there was severe liquid maldistribution throughout the column. Compositional gradients caused by poor initial liquid distribution were never corrected at lower elevations because the combined collector/distributor provides no remixing. A column that has one bad distributor and good mixing at the lower redistributors eliminates the propagation of the composition gradients down the column. In an effort to reduce investment and increase packing bed depth, a combined liquid collector and orifice pan distributor was used. An orifice pan distributor should never be used in large diameter refinery columns. The collector/distributor had a wide sump with a draw nozzle at one end. There were no drip points in the sump, leaving a large part of the packing without initial distribution. The pumparound collector/distributor also had a significant liquid gradient from the side opposite the pumparound draw to the draw nozzle. An attempt was made to modify the collector/distributors by installing drip tubes in the sump and using a second nozzle opposite the first. These modifications made little or no improvement in column performance.

Revamp Two: Fixing The First Revamp

Lyondell decided to perform a revamp of the packed column. A new design basis simulation was used to establish product

Design Product Yields, Second Revamp (BBL/D)

Products	Initial Revamp*	Second Revamp	Delta Yield
FCC Gasoline	49,397	51,797**	+2,400
LCO	25,983	23,583	-2,400
HCO	3,400	3,400	
Slurry	4,134	4,134	

* Actual Performance
** Gasoline TBP Endpoint, 455°F

Table 8

Design Heat Balance

	Pumparound Duty, MMBTU/hr	
	Initial Revamp*	Second Revamp**
Top	203	203
HCO	121	121

* Design Rate
** Same Internal Reflux Rates

Table 9

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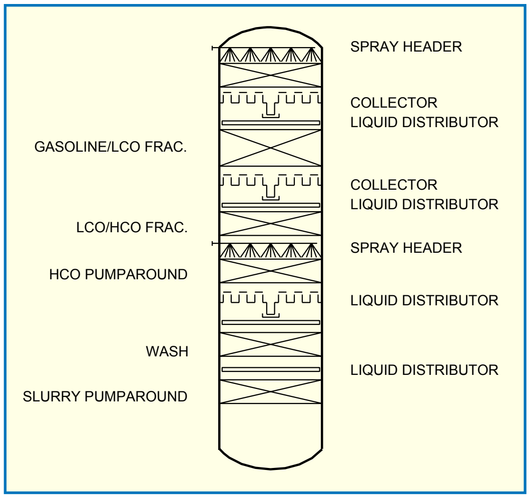

Figure 11 *Second Revamp*

yields and column design internal loadings.

Design/Installation

Table 8 shows the new, estimated design yields for the main fractionator. The raw gasoline design yield was based on a TBP endpoint of 455°F. The gasoline product yield improvements required better fractionation between gasoline and LCO. Modifying the collector/distributor would increase gasoline/LCO fractionation to four theoretical stages from one half of a theoretical stage. The second revamp heat balance is shown in Table 9.

The product quality comparison between actual performance and the second revamp design is shown in Table 10.

Design Product Qualities

	TBP Distillations, °F	
Raw Gasoline, Vol%	**Initial Revamp**	**Second Revamp**
50	262	269
70	317	325
90	393	401
95	424	426
EP	523	455
LCO, Vol %		
IBP	263	327
5	380	428
10	414	452
30	488	508
50	540	552
70	601	607
90	673	668
95	701	690
100	785	722

Table 10

Figure 11 illustrates the proposed second revamp design. The design uses separate liquid collectors and redistributors and less packing.

Good liquid distribution to a packed bed is important because packing does not redistribute liquid. A major misconception is that collector/distributor spacing should be sacrificed to increase packed bed depth. Approximately 25% of all refinery large diameter packed main fractionator revamps do not meet design objectives, primarily because of poor liquid collector and redistributor designs. In one case, the liquid collector design caused a major product yield loss on a vacuum column.[3] Packing HETP in large diameter main fractionators is controlled by liquid distribution quality. Good liquid distribution results in low HETPs. HETPs in large diameter refinery fractionators depend on the collector/redistributor system designs. When designing a liquid distributor for a 24-foot diameter column, the following items need to be evaluated:

- Liquid rate
- Distributor feed method
  - Feed pipe
  - Internal overflow from liquid collector (such as a pumparound or product draw)
- Mechanical requirements
  - Support
  - Installation
  - Leveling

Increasing liquid rate makes the distributor design more difficult. In a lube vacuum column or the LCO/HCO fractionating bed of an FCC, the liquid rates are approximately 0.5 to 1.5 gpm/sq ft^2 of tower area. In the gasoline/LCO section or the light/heavy naphtha section of an atmospheric pipe still, the liquid rates are 6-8 gpm/sq ft^2 of tower area.[4] The higher liquid rate distributors have very different momentum and horizontal velocity design considerations. At low liquid rates, these collectors/redistributors are easier to design.

Designing a large diameter distributor requires attention to detail. Liquid entering the parting boxes has momentum and the methods of feeding the parting boxes should minimize horizontal velocity. Aeration and horizontal velocity will cause poor liquid distribution; parting boxes should use some type of calming zone to reduce the effects of momentum. The liquid level in the parting box should be adequate over the entire operating range so that horizontal velocity is low.

Higher liquid rates require more elaborate and more costly distributor designs. Each design uses the same basic principles, but the specifics are different. All fractionation bed liquid distributors in this column are fed internally from collector trays (Figure 12). This is typical of refinery columns having multiple product draws and heat removals. Sections of the collector tray and the parting boxes and distributor troughs all form part of the liquid distributor system. The weirs feeding the liquid from the collector trays, parting boxes, and troughs were installed with water levels to ensure levelness. The distributor parting boxes and troughs were designed with independent level adjustments to ensure each part could be properly leveled.

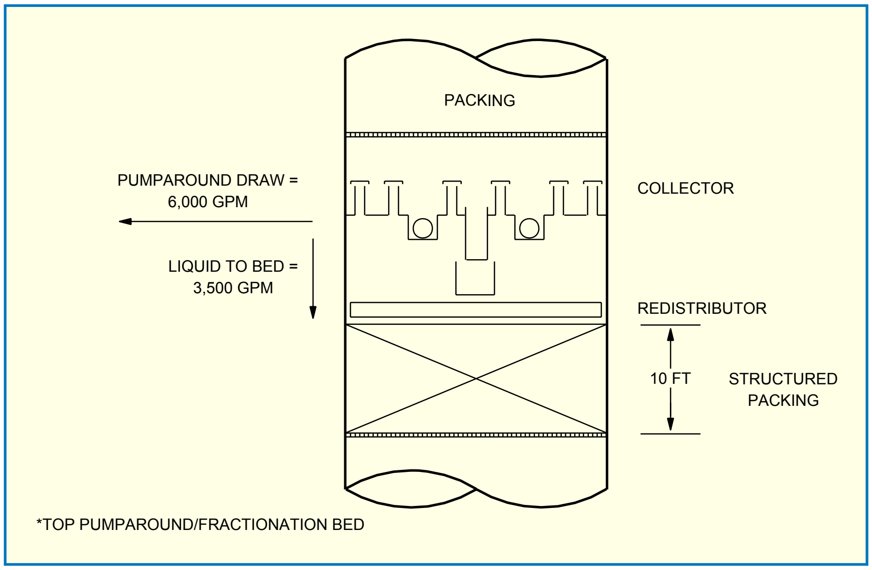

Figure 12 *Liquid Collector and Redistributor*

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***Photo 1** Thorough Packed Column Internals Inspection*

Distillation Curves, Raw Gasoline

	Trays	First Revamp	Second Revamp Design Basis	Second Revamp Actual Data
IBP	-82	-78	-78	-79
5	37	28	29	33
10	92	89	91	90
30	178	206	210	183
50	255	262	269	250
70	331	317	325	312
90	399	393	401	402
95	416	424	426	425
EP	442	523	455	446
Tail, 95-EP	26	99	29	21

Table 11

Field Inspection

A checklist of all the items to be field inspected was made before the shutdown. An experienced engineer should inspect the column internals before the manways are closed (Photo 1). Many columns fail because there is no one person responsible for this activity. A column should not be inspected by committee or by an inexperienced engineer because the job is critical.[5] Inspections also should not be made for the sole purpose of identifying that the equipment was manufactured per the drawings. Sometimes something is designed incorrectly, but built and installed correctly. The inspection is the last opportunity to catch mistakes that cause shutdowns (Photo 2). Many columns have to be shut down for modifications after a revamp, which is much more costly than correcting an error before start-up.[6,7]

***Photo 2** Final Inspection: Last Opportunity to Correct Mistakes*

Performance

The column internals were modified in early 1992. A thorough test run was planned to determine the actual packed bed efficiencies. Before the test run, the meters were zeroed and calibrated and the material balance checked. Once the material balance was acceptable, a heat balance around the fractionator was performed. The heat balance was acceptable; therefore, a full test run was scheduled. The unit was operated stably for 24 hours. A full set of stream samples were taken every 8 hours for laboratory analysis. Material and energy balances were performed on these three sets of data. The resulting data were then used to run the computer simulation. Lyondell's main fractionator has no metered reflux streams; therefore, consistent heat and material balance data was needed to determine the efficiency of the gasoline/LCO fractionation bed. It is easier to check the accuracy of the heat balance data on a main fractionator with external reflux from the overhead receiver because the reflux is metered. If the wash oil rate or another internal reflux stream is measured due to a total draw, then a good check of the column heat balance is possible. During the test run, the top pumparound duty was approximately 170 MMBtu/hr with a calculated internal reflux of about 2,500 gpm to the gasoline/LCO fractionating bed. The column was operated with lower than design internal reflux because the top pumparound heat removal was limited by pump circulation and exchanger problems. The top pumparound pumps will be modified during a future shutdown so that column internal reflux can be increased.

Table 11 shows the product qualities for the trayed column, initial revamp, and actual performance of the second revamp. The column has met design objectives (Table 12). The column now responds to operational changes and the product qualities reflect these changes.

Column Performance, NTS

Section	Trays*	Initial Revamp*	Proposed 2nd Revamp	Second Revamp*
Gasoline/LCO	3	<1	4	4
LCO/HCO	2	0	2	2
HCO/Slurry (Wash)	1	0	1	1

* Simulation of plant data

Table 12

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