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C_2 Splitter Revamp Surpasses Capacity and Efficiency of 4-Pass Trays

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A C_2 Splitter in Norco, Louisiana was successfully revamped with Shell HiFi™ Plus trays in 2015 for increased tray capacity. The HiFi Plus tray is a joint development between Sulzer and Shell and is relatively new to the marketplace. These trays are intended for large diameter and high pressure/high liquid loaded applications such as those found in Ethylene Production. Benchmarking the capacity and performance of such trays will be invaluable to the distillation industry. Operating data were taken both before and after the revamp and will be presented in the paper along with tray hydraulic information. This paper will address two main issues, capacity and performance of Shell HiFi™ Plus trays and the very important topic of comparing the new trays against the old 4-Pass tray design. Discussions will include the observed excellent tray efficiency, operational hydraulics and pressure drop of the new trays. In addition, unique features of the HiFi Plus tray will be discussed that enabled this tray efficiency to be achieved.

1. Introduction

Sulzer Chemtech and Shell have been providing tower internals for over 60 years. However, since March of 2000, Sulzer has been aligned with Shell Global Solutions to provide Shell HiFi™ Plus trays to the Chemical and Refining Industries. One of the opportunities that was enabled through this alliance was to revamp the C_2 Splitter (Item PV-1767) in Norco, LA in 2015. Prior to this revamp, the tower had operated for more than 35 years with conventional 4-Pass trays. The tower consisted of 154 stainless steel (410s) round valve trays in a 4877mm ID vessel situated at 508mm tray spacings.

The objective of the revamp was to fully utilize available hot side capacity and to provide additional tower capacity for future debottlenecking. In addition polymer grade ethylene purity had to be maintained with minimal ethylene losses in the bottoms. The tower is highly heat integrated into the whole Olefins Unit. The feed to the C_2 Splitter is a vapor stream from the overhead of the upstream Deethanizer. The feed point was located 37 trays from the bottom of the tower prior to the revamp. The ethylene product is drawn from a chimney tray located 10 trays from the top of the tower. There is also a side reboiler and the liquid draw and vapor return was located 32 trays from the bottom of the tower.

2. Operating Data Prior to the Revamp

Prior to the revamp, operating data were taken to examine the capacity and performance of the existing 4-Pass trays. The data were taken during several days of steady state operation in April 2015. Two particular days were “pushed” to high reflux rates and had steady operation for two days straight on the 26th and 27th of April. Since there was no feed analysis, the feed composition is based on the summation of the three product streams; Vent, Ethylene Products and Ethane Recycle. The overall material balance over those two days was excellent and within 3%, see column 1 in the below Raw Operating Data Table 1. Please NOTE - All flow rates in all the Tables have been “normalized” to match 1000.0 Kg/hr as the feed flow to the plant before revamp, as shown in Table 2 as the Feed. This “normalization” was enacted at the request of the operating plant. The tower was simulated using a proprietary Pro-II model using a Soave-Redlich-Kwong Equation of State VLE model. The data used to determine the proprietary interaction parameters was from Barclay, Flebbe and Manley (1982). This model was established within Sulzer's organization in the late 1990's and calibrated to actual operating data from several C_2 Splitters. The resulting Heat and Material (H&M) Balance is shown in Table 2. The difference in feed rate shown in Table 1 (compared to Table 2) is an indication of the unit's material balance, which is excellent and less than 5.6%. From this H&M balance, the internal loads and physical properties for all the 4-pass trays in the tower were generated and the key loads in each tower section examined with Sulzer's Hydraulics software program. Table 3 shows the results from an analysis for all four of the key tower sections.

As can be seen in Table 3, the Jet flood is very high in the Section above the feed (trays 38-144) and the downcomer velocity is very high in the Pasteurization Section. Because of the high loads in these two sections, the tower was highly loaded in 2015 and the plant was correct in their assessment that this tower was a bottleneck. Also of note, the observed pressure drop of the existing trays was also very high, see Table 1, at 1.1KPa per tray. This very high pressure drop (including the vapor head) could be considered an indication of flooding across some of the trays.

Table 1: Raw Operating Data C2 Splitter PV-1767

Item Description	Tag No.	Units	April 2015 Before Revamp	Feb 2017 After Revamp
Feed Rate* (normalized)	FF-5758A	kg/hr	1055.83	1142.1
Feed Temp	TI-6147	°C	-9.5	-2.1
Top Pressure	PT-5416	KPag	2194.5	2325.6
Delta-P	PDI-5414	Kpa	170.3	99.3
Bottom Flow Rate	FT-5164	kg/hr	405.55	360.75
Reflux Drum Pressure	PI-5415	KPag	2193.9	2324.9
Reflux Drum Temperature	TI-6257	°C	-27.1	-20.9
Reflux Flow	FI-5420	kg/hr	3503.1	4003.17
Vent Flow	FI-5425	kg/hr	42.09	46.34
Side Reb. Duty	Calculated	MMKJ/Hr	22.1	25.3
Ethylene Draw	FC-5154	kg/hr	576.4	722.2
Ethylene Product - Ethane	AI-5417A	ppm	486.7	504.4
Ethylene Product - Methane	AI-5417B	ppm	37.34	1.3
Splitter Vent - Hydrogen	AI-5424A	%	0	0.93
Splitter Vent - Methane	AI-5424B	%	1.9943	0.075
Bottom Product - Ethylene	AI-5427	%	1.8808	4.52

*Table 2: Heat and Material Balance – Pre-Revamp Simulation Results (*normalized flows)*

Composition, wgt%	Feed	Vent	Ethylene Product	Ethane Bottoms
Hydrogen	0.0003%	0.0075%	0	0
N_2	0.0453%	1.2658%	0.0017%	0
Methane	0.0498%	1.1160%	0.0049%	0
Ethylene	62.40%	97.606%	99.942%	1.751%
Ethane	37.15%	0.0046%	0.0522%	97.318%
Propylene	0.2131%	0	0	0.559%
Propane	0.0000%	0	0	0
IsoButane and Heavier	0.1421%	0	0	0.372%
Total (kg/hr)*	**1000.0***	**42.09**	**576.47**	**381.44**
Phase	Vapor	Vapor	Liquid	Liquid
Temperature, °C	-9.86	-25.7	-23.9	0.5
Pressure, KPag	2550	2193.1	2203.5	2364
Reflux Drum Pressure	2193.1	KPag		
Tower Top Pressure	2193.8	KPag		
Reflux Rate	3503.25	kg/hr		
Reflux (Bubble Point) Temp.	-25.7	°C		
Top Temperature	-24.5	°C		

Table 3: Tray Hydraulics of the Pre-revamp 4-Pass Trays

Trays	Tray Count	Section Name	Jet Flood %	Weir Loading m3/m-hr	DC Velocity m/sec	Pressure Drop KPa/Tray
145-154	10	Pasteurization	82	73.0	0.106	0.543
38-144	107	Above Feed	87	63.7	0.092	0.520
33-37	5	Above Side Reboiler	65	63.7	0.092	0.375
1-32	32	Bottom	54	55.2	0.079	0.355

3. Revamp

For the Ethylene plant to realize the premised improvement in ethylene production, several features to the plant were upgraded in 2015. One of them was to debottleneck the C_2 Splitter, PV-1767. Shell did a full study of various feed slates to the tower as well as optimizing the feed point and side reboiler location. This study included the full revamp of all trays on a tray-for-tray basis from the very old 4-Pass trays to the modern Shell HiFi Plus trays. The reboiler was also upgraded. The old trays from 1978 had straight side downcomers and box-type straight center and off-center downcomers that wasted a significant amount of tower cross-sectional area. In addition, these trays were designed in an era when 4-pass tray balancing was not even considered important. Four pass tray balancing became very important in the new millennium as shown by the referenced article by Summers in 2009. There was a significant opportunity for a vast capacity improvement of this tower.

With adjustments to upstream cracking, the feed ethylene purity would become higher in ethylene content as well as higher in overall throughput. The feed tray was moved higher in the tower to above tray 45 (counted from the bottom) and the side reboiler draw and return location moved up to tray 37 as well. Note that the old liquid withdraw nozzles for the side reboiler were used after the revamp and that internal piping was used to get the liquid from tray 37 down to tray 32 for withdraw. HiFi Plus trays were chosen because of positive past experience in C_2 Splitter service as depicted in the referenced publication by Summers, et al from 2007. These trays are comprised of multiple sloped and truncated downcomers with active tray deck area between. The prominent feature of the HiFi tray is its long weir length which enables high liquid loaded systems to operate at reduced weir loading and achieve high capacity, see Figure 1. The other prominent feature is a defined flow path length which enables this tray to achieve very good tray efficiencies.

Figure 1: Two Half-Tray Trial Layouts of the HiFi Plus Tray for PV-1767

The revamp of the tower took a just little more than 30 days and was not encumbered by a single safety incident. To expedite the revamp of all 154 trays, elevators (instead of cranes) were employed to keep tray parts moving to and from the tower even in inclement weather, see Figure 3. The elevators also enabled, during the peak of activity, to have internals installed concurrently at five working zones in the column. In addition to a HiFi revamp, Chimney trays and all feed devices were changed out as well. To ensure adequate spacings for capacity two active trays were converted to chimney trays resulting in 152 HiFi Plus trays in the tower.

4. Operating Data after the Revamp

After the HiFi tray revamp, operating data were again taken to examine the capacity and performance of the new trays. The data were taken over several days of steady operation in early 2017, see Figure 2. One particular day, February 7, 2017 was very steady for not just the reflux, but the other flow rates, and was chosen for this study. Again the feed composition is based on the summation of the three product streams; Vent, Ethylene Products and Ethane Recycle. The overall material balance over this day of operation was excellent and within 1%, see column 2 in the Raw Operating Data Table 1. To match the reflux rate on this date, Murphree Tray efficiency values where employed in Pro-II to the trays in the tower and the overall efficiency adjusted. The trays showed a higher efficiency (82.6%) than the old 4-Pass trays (78.3%). The resulting Heat and Material (H&M) Balance is shown in Table 4. The difference in feed rate shown in Table 1 (compared to Table 4) is an indication of the unit's material balance, which is excellent and less than 1.2%. From this H&M balance the internal loads and physical properties for all the HiFi trays in the tower were generated and the key loads in each tower section examined with Shell's Hydraulics software program. Table 5 shows the results from that analysis for all four of the key tower sections. As can be seen in Table 5, the Jet flood and the downcomer velocities in the two upper sections are no longer a problem. In fact, the tower is quite under loaded and has plenty of extra capacity. There was one thing to note, the pressure drop across the trays reduced significantly from 170.2 KPa before the revamp to 99.2 KPa after. This is also a clear indication there is plenty of extra capacity in this tower. The calculated pressure drop in Table 5 is 57.8 KPa. The vapor head across the 91.5 meter tall tower is approximately 42 KPa. This gives us a 99.8 KPa predicted pressure drop that matches the observed value quite accurately.
Condenser and refrigeration capacity limitations were intentionally not addressed in this project, and have, as expected, limited the utilization of the full hydraulic HiFi tray capacity to date.

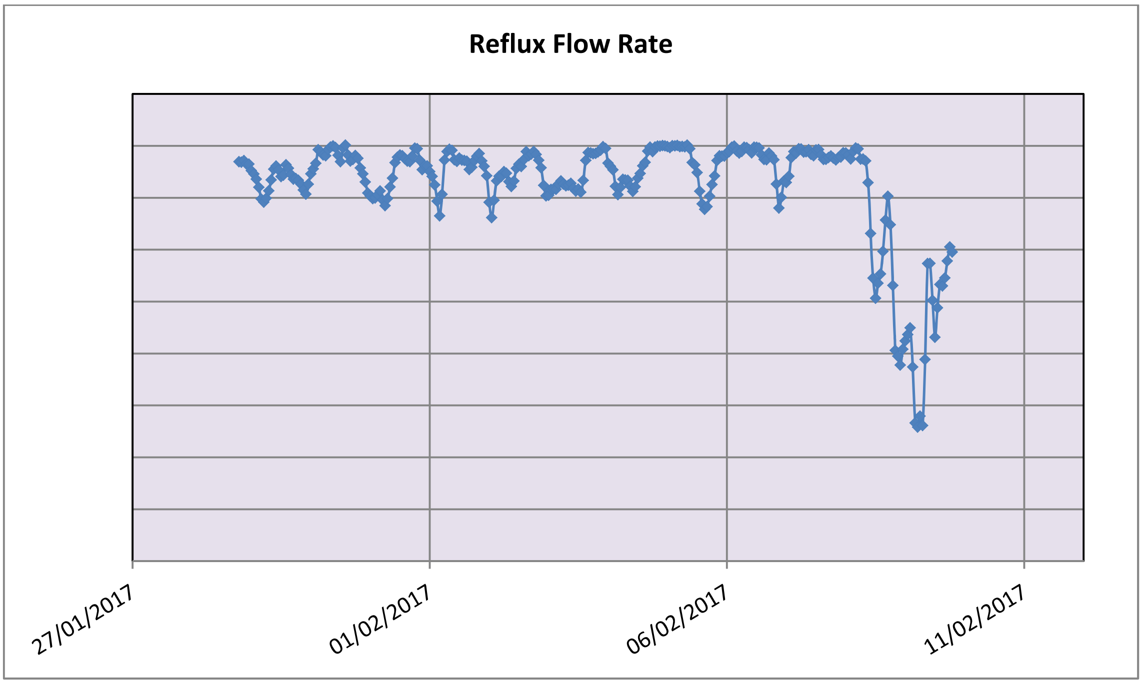

Figure 2: Steady Sate Determination – Operating Reflux data after the Revamp

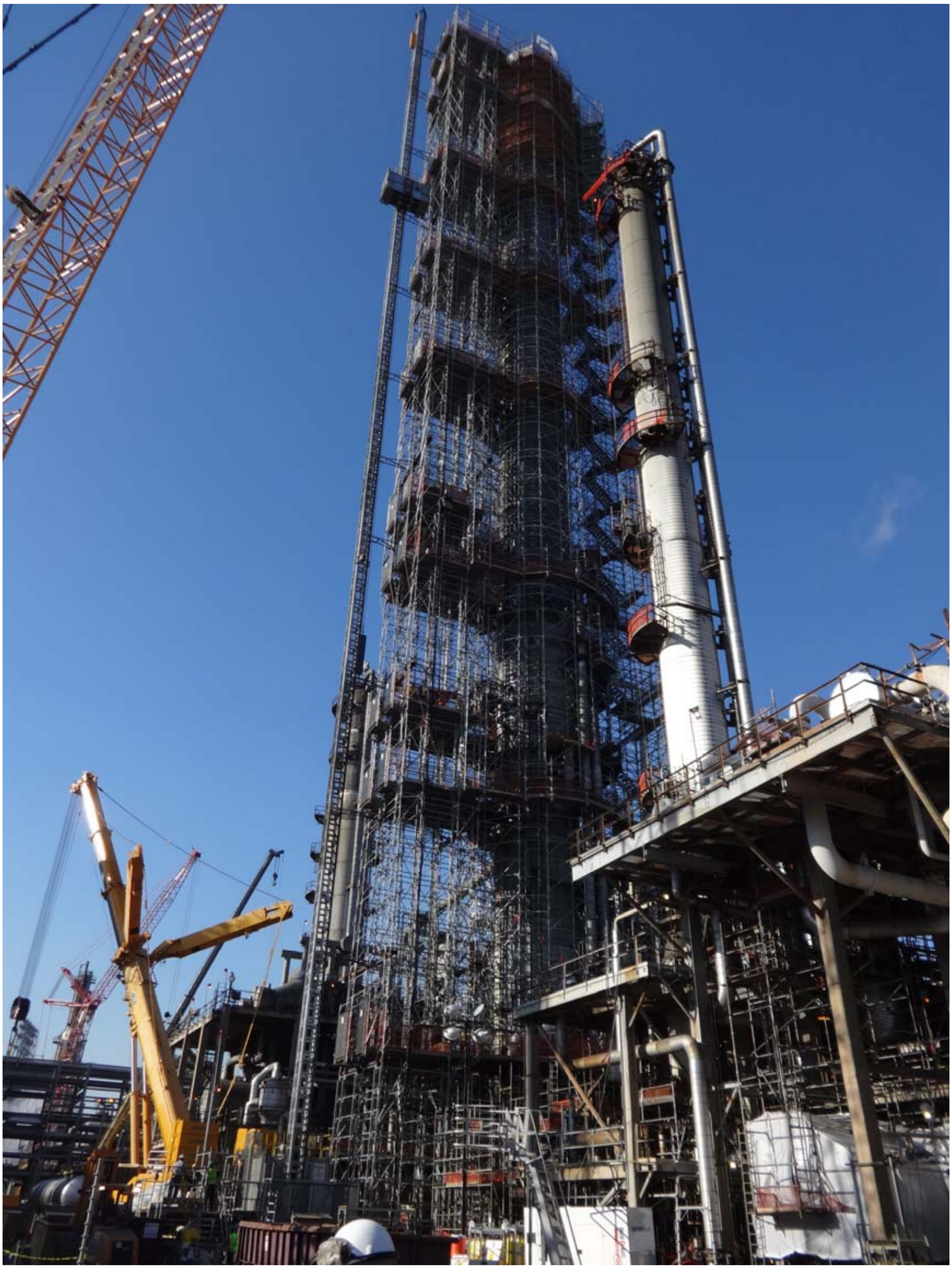

Figure 3: C_2 Splitter being Revamped – Note the construction Elevator attached to the Vessel

*Table 4: Heat and Material Balance – After Revamp Operation Simulation Results (*normalized flows)*

Composition, wgt%	Feed	Vent	Ethylene Product	Ethane Bottoms
Hydrogen	0.0003%	0.0074%	0	0
N_2	0.0525%	1.2504%	0.0018%	0
Methane	0.0009%	0.0198%	0.0001%	0
Ethylene	69.30%	98.717%	99.944%	4.2135%
Ethane	30.34%	0.0057%	0.0540%	94.840%
Propylene	0.1833%	0	0	0.5736%
Propane	0.0000%	0	0	0
IsoButane and Heavier	0.1192%	0	0	0.3731%
Total (kg/hr)*	**1129.3***	**46.34**	**722.2**	**360.8**
Phase	Vapor	Vapor	Liquid	Liquid
Temperature, °C	3.4	-22.8	-21.9	0.83
Pressure, KPag	2757	2324	2329.6	2428.1
Reflux Drum Pressure	2324.0	KPag		
Tower Top Pressure	2324.8	KPag		
Reflux Rate	4003.66	kg/hr		
Reflux (Bubble Point) Temp.	-22.8	°C		
Top Temperature	-22.1	°C		

Table 5: Tray Hydraulics of the HiFi Plus Trays

Trays	Tray Count	Section Name	Jet Flood %	Weir Loading m3/m-hr	DC Velocity m/sec	Pressure Drop KPa/Tray
145-154	10	Pasteurization	66.2	43.8	0.0735	0.415
47*-144	98	Above Feed	64.7	36.6	0.0606	0.391
38-45	8	Above Side Reboiler	53.0	36.6	0.0600	0.364
1-37	37	Bottom	44.8	32.2	0.083	0.336

*Tray 46 became a chimney tray

5. Conclusions

The revamp of the Norco, Louisiana C_2 Splitter (PV-1767) with 152 Shell HiFi Plus trays resulted in a significant improvement of tray efficiency and capacity. The plant, independently, reports that the energy usage in both the side reboiler and bottom reboilers decreased by 6% on an energy per mass of product basis. However, a comparison of the total reboiler duty between Tables 2 and 4 indicate that the decrease is closer to 15% based on the data presented here.

The tower also has about 20 to 25% extra capacity available for the future based on employing a maximum jet flood of 85% as the column's limitation. Tray efficiency is very consistent with previous HiFi Plus applications in high-pressure service. Predicted pressure drop for the HiFi Plus trays match operational values extremely well.

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