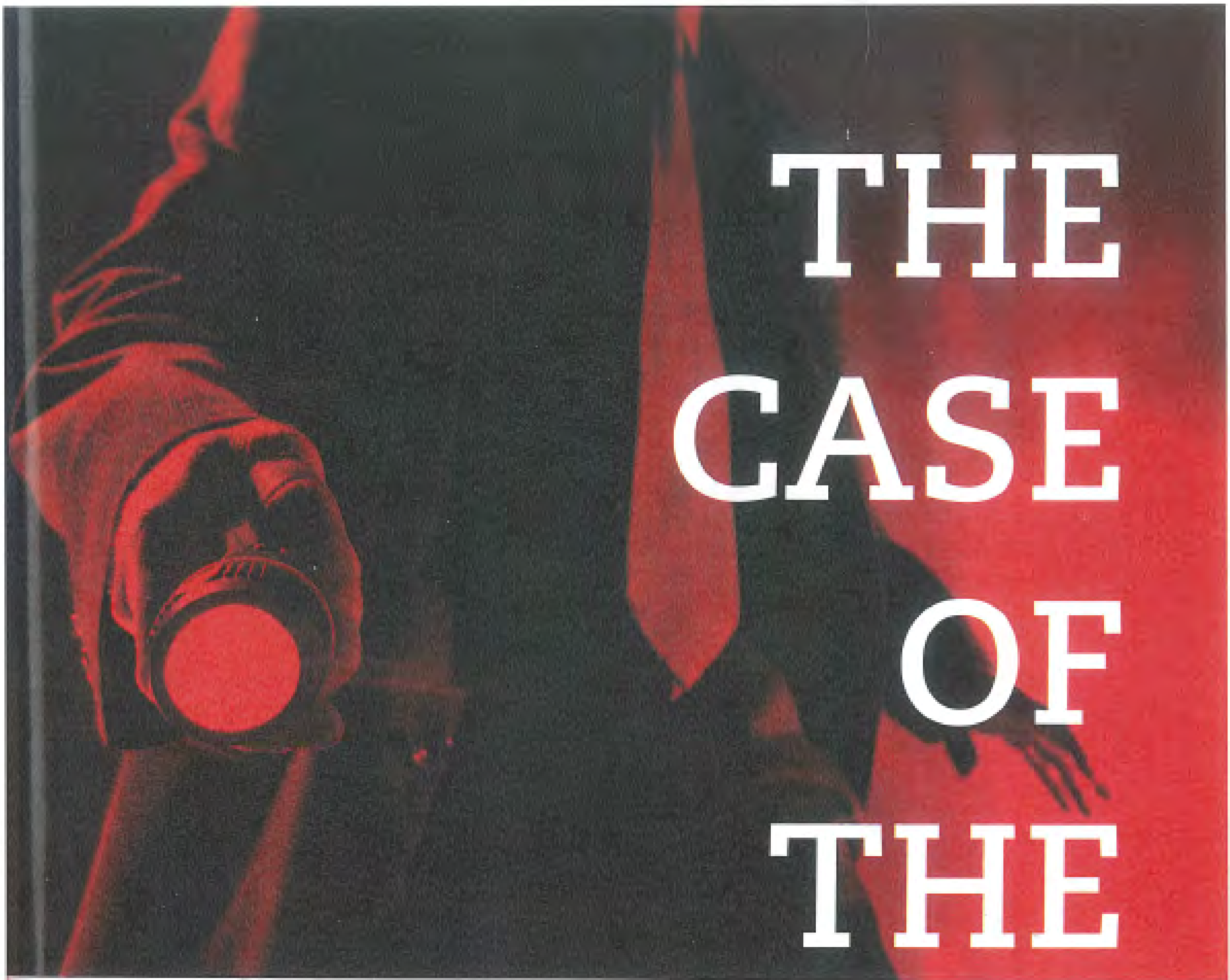

THE CASE OF THE 'MISSING' HAGO

ZVI MERCHAV, MERCHAV ENGINEERING, ISRAEL, AND FRED JUSTICE, CHEMSTATIONS, USA, INVESTIGATE THE PROCESS OF TROUBLESHOOTING A CRUDE UNIT MAIN COLUMN AT A REFINERY.

This article describes how a process simulator was successfully used to analyse and troubleshoot a problem in a process unit, specifically a crude unit, and details how the client attempted to solve the problem, how a computer simulation helped identify the problem, and how a gamma scan confirmed the diagnosis.

The story begins in 2009, when a refiner completed a revamp and turnaround project. The turnaround included the installation of a prefractionation column, modifications to the heat train, and modification and replacement of some pumps.

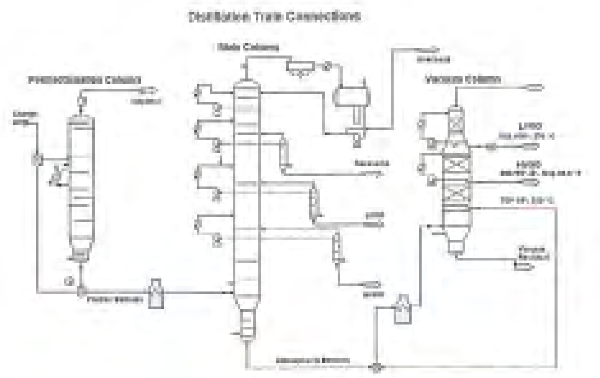

Figure 1. Flowsheet diagram showing configuration of columns.

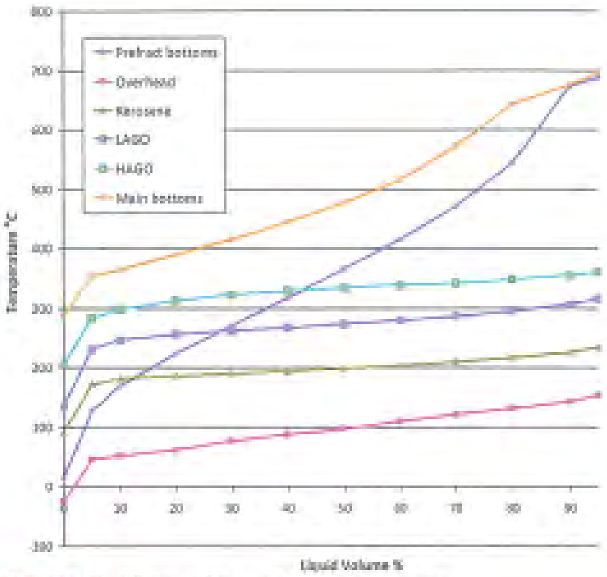

Figure 2. Main D86 distillation curves.

Table 1. Summary of column configuration

		Prefractionation	Main column	Vacuum
Configuration	Side strippers		3	
	Pumparounds	1	4	3
	Side products			3
Main column	Stages	20	38	14
	Top pressure (barg)	3.7	0.4	-0.9935
	Pressure drop (bar)	0.34	0.37	0.014
	Reflux to stage no.	1	1	#3 pump to 1
	Feed tray no.	12	35	12
Side stripper	Tray no/steam		#3 kerosene	
			#20 LAGO	
			#29 HAGO	
Side products	Tray no/steam			#3 LVGO
				#8 HVGO
				#12 Recy

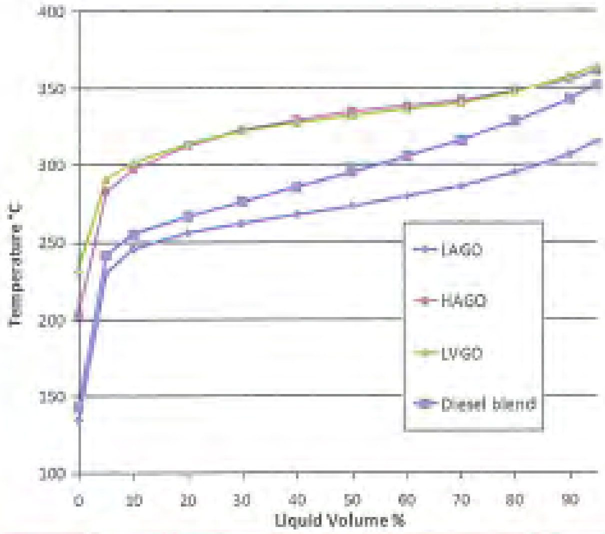

Figure 3. Diesel blend D86 distillation curves.

A booster pump was added to overcome the additional pressure drop that resulted from the capacity increase. The main column trays were modified, mainly due to lower loads in some scenarios, and packing beds in the vacuum column were replaced.

The vacuum system was also modified to allow the usage of velocity steam in the vacuum heater and the introduction of stripping steam to the vacuum column bottom. Figure 1 shows the arrangement of the preflash main and vacuum columns, and Table 1 gives a summary of the columns.

After turnaround, the unit was started up with no unexpected difficulties; except for some occasional clarifications regarding new operating conditions, nothing seemed out of the ordinary. The feed rate to the unit exceeded the design capacity by more than 10%. The refiner did not want to further increase the feed rate due to concerns about tube side velocity in some of the exchangers.

The distillation curves for the feed and other streams of interest are plotted in Figure 2. The product yields and specifications were as predicted and expected by the customer.

Diesel product is usually a blend of three crude unit products: light atmospheric gas oil (LAGO), heavy atmospheric gas oil (HAGO) and light vacuum gas oil (LVGO). The proportion of the blend is varied to meet a particular product specification, which can vary slightly depending on its usage during winter or summer. The typical stream distillation curves are shown in Figure 3.

The problems begin

Approximately a year and a half after start up, the unit's output began to change. The operators could no longer maintain the required diesel specification under normal conditions. The only way they could meet the specification was by modifying the operation in a way that severely affected the operation of the vacuum column and the main column temperature profile. This produced a huge effect on heat recovery in the pumparounds, and therefore on fuel consumption in the heaters. Something must have happened with the operation of the unit, but no one understood what caused this change in performance.

The problem that the refiner experienced was a drop in HAGO yield, combined with an LVGO yield increase. If the same HAGO yield was kept, the diesel 95% D86 point exceeded the maximum allowable value, which in this case was 360 °C. To achieve the desired diesel blend D86 95% point, both the HAGO and LVGO D86 95% points would need to remain at or below 360 °C.

Table 2. Distillation profile for main column (problematic tray locations marked in red)

Stage	Temp (°C)	Pressure (barg)	Liquid (kg/hr x 10^3)	Vapour (kg/hr x 10^3)	Feeds (kg/hr x 10^3)	Product (kg/hr x 10^3)	Duties (kcal/hr x 10^6)
1	62	0.35	0.1	0.0	6.0	90.8 side prod 16.7 water	15.2
2	108	0.4	451.2	101.6	330.5 PA return		15.4
3	124.4	0.41	495.5	222.2			
4	133.3	0.42	184.3	266.6		330.5 PA draw	
5	142.6	0.43	188.7	285.9			
6	147.8	0.44	189.8	290.3			
7	151.5	0.45	189.4	291.4			
8	154.7	0.46	187.8	291.0			
9	158.2	0.47	184.3	289.4			
10	162.7	0.48	177.2	285.8			
11	169.8	0.49	474.5	278.7	228.8 PA return		7.0
12	176.9	0.5	486.0	347.2	7.1 PA return		
13	184.2	0.51	176.2	351.5		228.8 PA draw 76.6 side stripper draw	
14	198.1	0.52	171.8	347.2			
15	208.1	0.53	169.0	342.8			
16	215	0.54	164.7	340.1			
17	220.6	0.55	156.2	335.7			
18	226.7	0.56	238.6	327.3	47.6 56.7 PA return		-3.0
19	234.4	0.57	232.8	353.0	6.3 PA return		
20	242.3	0.58	69.6	340.9		56.7 PA draw 87.9 side stripper draw	
21	254.7	0.59	60.4	322.2			
22	260.7	0.6	55.8	313.0			
23	263.4	0.61	52.7	308.5			
24	265	0.62	50.1	305.4			
25	266.1	0.64	47.5	302.7			
26	267.1	0.65	44.8	300.2			
27	268.1	0.66	520.0	297.4	386.5 PA return		-14.5
28	281.7	0.67	558.8	386.2	5.3 PA return		
29	292.5	0.68	137.5	419.7		386.5 PA draw 47.4 side stripper draw	
30	305.8	0.69	131.2	432.2			
31	311.8	0.7	123.4	425.9			
32	315.4	0.71	115.6	418.2			
33	318.2	0.72	106.4	410.3			
34	320.8	0.73	91.9	401.1			
35	324.6	0.74	56.3	386.7	564.4 feed		
36	349.4	0.75	364.3	303.5			
37	345.6	0.76	345.3	47.0			
38	338.6	0.77	0.0	28.0	7.9 steam	325.2 bottoms	

Attempting to overcome the problem, the operators tried various ideas, including increasing the main column charge heater outlet temperature. These changes were intended to increase or reduce the liquid flow rate below the HAGO drawoff tray. It was clear that this approach was having no positive effect; HAGO yield remained below the desired flow rate. It was clear that something was wrong below the HAGO stripper draw tray.

The refiner eventually settled on a strategy to allow a large proportion of HAGO to drop into the atmospheric bottoms stream, which is fed to the vacuum column. This modification had significant consequences for the vacuum column: since more light material entered the vacuum column, it was not possible to control the column pressure. In addition, the capacity that the column could handle was affected so that the HVGO production had to be reduced. The reduction of HVGO was achieved by allowing HVGO to drop into the vacuum bottoms. This change increased the feed rate to the visbreaker, and affected the quality of the HVGO and FCC unit yields. The various workarounds and their downstream effects made a significant negative impact on the refinery's economics.

After struggling with the problem, the refiner's technology vice president asked (only half joking): 'who is stealing all my HAGO?' The plant manager provided a more detailed description of what the unit operators were seeing. Merchav Engineering, the engineering consultants who had performed the revamp design, were called in to help find the problem.

To help with the diagnosis, the refiner provided the crude assays and crude mix recipe, along with laboratory data, product yields and control room screen prints. The consultants already had a CHEMCAD simulation model of the process, which had been calibrated to test run data and was able to accurately simulate performance of the unit. The model included heat exchanger thermal design with fouling factors, pump curves, column tray and packing design, and detailed piping hydraulics. Because the company had both experience with the column network and accurate models at design conditions, Merchav was able to begin troubleshooting this problem with little lead time.

Simulating the column

The first step was to calibrate the CHEMCAD simulation model with the current plant data. This was not an easy task, because the data provided was not of 'test run' quality. After the refiner provided some clarification, the model was calibrated quite well. When the refiner agreed that the simulation model described the plant well, the simulation was manipulated in several ways to start tracking down the problem.

The first attempt was to change the main column charge heater outlet temperature, as the operators had done. It was observed that the production of HAGO did respond as expected, but did not match operating data. This was one of the first clues for solving the mystery of off spec performance. Various other modifications were made to mimic different attempts made by the operators.

For the main column, the 'as designed' profile is presented in Table 2. The consultants began to suspect that something was obstructing the trays' operation between the HAGO draw tray and the flash zone: this would result in reduced tray efficiency in that column section, which might provide an explanation for the problems. The HAGO product properties flow rate and D86 90 to 100% points are shown in Table 3.

Now that obstruction was suspected as the cause of reduced tray efficiency, changes to the simulations were focused on determining the influence of tray efficiency of the trays (no. 30 – 35) just below the HAGO draw tray. This was done to see whether holding the D86 95% point at specification could account for loss of HAGO. When the tray efficiency was set at 50% and the product specification was kept at D86 95% 360 °C, the simulated roduct flow rate dropped from 49 Sm^3/hr to 38 Sm^3/hr (columns 1 and 2, Table 3).

The measured flow rate of the HAGO in the unit had dropped to approximately 10 Sm^3/hr. The efficiency reduction in the simulation could not explain this dramatic change, but the simulated flow rate change was in the right direction, which seemed to indicate that the approach was correct.

The next attempt was to set the tray efficiency at 25%, but the tower did not converge; the column could not make any HAGO product with the required D86 specification. When the tray efficiency was set to 35%, the HAGO product flow rate was calculated to be approximately 9.6 Sm^3/hr, which was very close to the reported rate of 10 Sm^3/hr. A possible explanation for the off spec yield of HAGO had been found: reduced tray efficiency.

The estimated actual design tray efficiency for the main column was 75%. This was confirmed by the calibrated tray efficiency of the test run simulation, which was calculated at approximately 75%. Since the simulation that matched the observed performance in that suspicious zone was calculated at very low tray efficiencies, it was clear that the trays were not functioning as they should. Possible explanations for such a drastic reduction in efficiency were that some trays had been partially or completely knocked out, or that debris had accumulated on the trays.

After some discussion, a temporary workaround to the operation was recommended. The refiner would draw the LAGO together with the HAGO from the LAGO stripper, since these two products are blended together with the LVGO to make the diesel product. As a result of this recommendation, the HAGO pumparound and HAGO product stripper were not in operation. The modification had some effect on the heat recovery, since heat was shifted to the three other column pumparounds and the tower temperature profile changed. This resulted in lower temperature differences in certain exchangers. For the suspect trays, it was judged highly likely that the trays in that section would need to be replaced, and such a change would require a shut down.

Further testing

The refinery management also decided to make a gamma scan of the column to confirm these thermodynamic simulation findings before the next shut down. In gamma scanning, 'a small adequately sealed radioactive source and a detector are moved down simultaneously, with a small increment, on

Table 3. Comparison of calculated HAGO outputs to reported results

	Trays 30 – 35			After reported output
Assumed tray efficiency	100%	50%	35%	
Name	HAGO	HAGO	HAGO	
Molar flow (kmol/hr)	159.1	124.9	31.1	
Mass flow (kg/hr)	42 520.1	33 192.50	8281.90	
Temp (°C)	283.3	280.3	260.2	
Pressure (barg)	0.676	0.767	0.676	
Vapour mole fraction	0	0	0	
Tc (°C)	512.6	511.2	511.7	
Pc (barg)	15.01	15.08	15.34	
Degree (API)	31.87	32.00	31.95	
Average mol wt	267.1	265.6	266.0	
Actual density (kg/m^3)	US$ 679.1	US$ 680.5	US$ 697.2	
Actual vol (m^3/hr)	62.6	48.8	11.9	
Std liq (m^3/hr)	49.09	38.35	9.57	10
D86 90% (°C)	355.1	353.3	349.0	
D86 95% (°C)	360.0	360.0	360.0	
D86 100% (°C)	364.9	367.7	371.0	

opposite sides along the column. A profile of relative density of the column's content is obtained. By analysing the obtained profile and comparing it to a mechanical scheme of the column, some conclusions can be deduced concerning the possible mechanical damages of the trays as well as some working conditions of the column, like obstructions, blockages, or other process's abnormalities."[1]

Analysis of the chimney tray gamma scan indicated that the chimney tray, overflash draw sump and overflash line were likely drying up. Strong evidence was also found of displaced or dislodged metal in the vapour space immediately below the chimney tray.

For the trays below the HAGO draw and the chimney tray, the gamma scan report indicated irregular peaks in the volume which should be occupied by five physical trays. This pattern suggested dislodged tray parts or drying and entrainment. The scan of lower trays indicated that those trays appeared to hold a reasonable liquid head; this was inconsistent with the theory that drying trays was the reason for the irregular scans just below the HAGO draw.

Thus, the irregular scans of the volume below the HAGO draw, and the more normal results for the volume further below, confirmed the theory that the trays in this area had likely suffered a mechanical malfunction and were therefore not contributing to effective vapour/liquid contact. This would account for both greatly diminished tray efficiency and irregular gamma scans.

During a short duration turnaround to replace the trays, it was found that the trays in question were, in fact, dislodged and damaged. The trays were replaced and the unit went back on stream.

Conclusion

A sudden change in column performance required an analysis, which was performed in steps to identify the cause of the disturbance. A first principles process simulation model that matched control room data provided important clues about the malfunction. This in turn justified the additional expense of a gamma scan to move toward verification of the problem. The interpretation of gamma scan data allowed the operating company to be prepared for renovations and repairs during a quick turnaround. After repair, the distillation train once again performed as designed. Comparing the results of a calibrated simulation before and after an upset was found to be the least costly and disruptive method to suggest the nature of the upset and suggest a remedial strategy for the column.

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