

Crude-Quality Drift and Flexible CDU Operation: Nile Blend Case Study

Mohamed Omer Mohamed Elnaeem¹

¹ Petroleum Engineering Department, Sudan University of Science and Technology, Khartoum, Sudan

Correspondence: Mohamed Omer Mohamed Elnaeem, Petroleum Engineering Department, Sudan University of Science and Technology, Khartoum, Sudan.

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Abstract

Atmospheric crude distillation units are often designed for a bounded crude quality envelope, yet mature-field production and blend variability can progressively shift feed properties and degrade yield performance. This study develops an integrated assay-simulation-plant-evidence framework to quantify the impact of Nile Blend crude quality drift on atmospheric crude distillation and to identify practical operating-flexibility levers. Multi-year assays show a decline from 34.81 to 30.58°API between 2006 and 2011, accompanied by a density increase from 850.4 to 872.3 kg/m³, an 80% endpoint increase in measured salt content, and a maximum TAN of 0.59 mg KOH/g. Product-yield variability was operationally significant: naphtha varied by 6.64 percentage points, diesel by 4.15 percentage points, and atmospheric residue by 8.89 percentage points. The Aspen HYSYS model reproduced benchmark product flows with maximum error of $5.32 \times 10^{-5}\%$ and matched TBP-derived yield patterns with MAE of 0.39 vol% and RMSE of 0.74 vol%. Plant comparison revealed average naphtha and kerosene shortfalls of 0.70 and 3.86 wt%, respectively, relative to assay potential. Feed-entry strategy was the strongest modeled lever, increasing naphtha by 15.3 percentage points and reducing residue by 15.3 percentage points across the tested range. Reflux adjustment provided a smaller but field-accessible control lever. The results establish an assay-driven, model-updated surveillance workflow for managing crude quality drift without premature hardware retrofit.

Keywords: crude distillation unit, Nile blend, crude-quality drift, API gravity, Aspen HYSYS, true boiling point assay, atmospheric residue, refinery optimization

1. Introduction

Atmospheric crude distillation is the primary separation operation in petroleum refining and the first process step that converts crude-oil quality into refinery product opportunities and constraints. The crude distillation unit (CDU) allocates feed into light ends, naphtha, kerosene,

diesel, atmospheric gas oil, and atmospheric residue. This first split governs preheat recovery, furnace duty, side-stripper loading, hydrotreating severity, conversion-unit feed availability, product blending, storage, and residue management. For refineries with limited conversion depth, a modest shift in the CDU product slate can have disproportionate

economic consequences because atmospheric residue has lower value and higher downstream handling requirements than light and middle distillates (Gary, J. H. & Handwerk, G. E., 2001; Jones, D. S. J. & Pujado, P. R., 2006; Wauquier, J. P., 2000; Parkash, S., 2003).

A practical difficulty in CDU operation is that crude oil is not a fixed feedstock. Mature fields, changing well contributions, upstream blending, water handling, reservoir depletion, and production-history effects can alter API gravity, density, true boiling point (TBP) distribution, water content, salt content, total acid number (TAN), sulfur content, and heavy-end concentration. Commercial crude streams may retain the same blend name while their distillation behavior changes enough to affect product yields and product-quality control. Therefore, CDU performance should be treated as a dynamic function of crude quality rather than as a fixed consequence of original design.

The engineering literature has established the importance of crude assay characterization, vapor-liquid equilibrium, reflux, stripping, pumparound heat removal, and column hydraulics for distillation performance. Process simulators such as Aspen HYSYS are widely used to evaluate refinery flowsheets, crude scheduling, design alternatives, and operating sensitivities. However, the critical engineering challenge is not simply reproducing a CDU in a simulator. The more valuable task is integrating assay data, simulation output, and plant yield performance into an actionable operating framework that distinguishes unavoidable feed-quality effects from recoverable operating losses (Zhang, N. & Zhu, X. X., 2000; Chrysosolouris, G., Papakostas, N. and Mourtzis, D., 2005; Pan, M., Li, X. and Qian, Y., 2009; Robertson, G., Palazoglu, A. & Romagnoli, J. A., 2011; Benali, T., Tondeur, D. & Jaubert, J. N., 2012; Aspen Technology, 2004; Aspen Technology, 2005a; Aspen Technology, 2005b; Aspen Technology, 2005c).

Recent refinery digitalization work further supports this surveillance concept. Flexible CDU design can be accelerated with neural-network and support-vector-machine surrogate models, while recent bi-level surrogate optimization and AI-assisted crude scheduling studies show how rigorous process models can be updated or screened efficiently for changing feed slates. These developments position the proposed

assay-HYSYS-plant workflow within current Industry 4.0 practice for digital twins, model-updated operating windows, and real-time or near-real-time decision support (Ibrahim, D., Jobson, M., Li, J. & Guillén-Gosálbez, G., 2021; Xiong, Y., Shi, X., Ma, Y. & Chen, Y., 2023; Zhang, W., Du, W., Yu, G., He, R., Du, W. & Jin, Y., 2024; Alizadeh, S., Ta, S., Ray, A. K. & Samavedham, L., 2023; Abdullah, A. S. & Ayoob, H. W., 2023).

Nile Blend processing at Khartoum Refinery provides a technically useful case for this purpose. The available evidence includes multi-year crude assays, TBP product-yield data, KRC plant yield information, and Aspen HYSYS cases. The data show a meaningful crude quality shift during the evaluation period, with API gravity declining, density increasing, and corrosion/desalting indicators changing. The product slate also changed substantially, especially in naphtha and atmospheric residue. These observations raise a refinery-engineering question: how much of the yield deterioration is inherent to crude quality drift, and which operating or design levers can recover light-product value?

This manuscript advances the analysis by combining the numerical rigor of the earlier detailed manuscript with the sharper technical framing of the alternative draft. The final contribution is an integrated assay-HYSYS-plant assessment of crude quality drift and CDU flexibility. The manuscript emphasizes quantitative diagnostics, refined interpretation of tray and reflux effects, and field-applicable decision logic. Particular attention is given to avoiding over-simplified retrofit recommendations; the results are interpreted as a basis for controlled plant testing, operating-window adjustment, and calibrated digital surveillance.

The objectives are to quantify Nile Blend crude quality drift, measure the effect of crude variation on CDU product-yield distribution, validate the HYSYS model against benchmark and TBP evidence, diagnose plant-yield deviation relative to assay potential, rank feed entry, tray number, and reflux-ratio sensitivities, and define practical field application implications for refineries processing variable crude slates.

2. Materials and Methods

The analysis used three complementary evidence streams: crude assay data, Aspen HYSYS process

simulation, and KRC plant-yield comparison. Historical Nile Blend assay data covered multiple years between 2002 and 2012, with detailed property and product-yield interpretation focused on 2006, 2007, 2008, 2009, and 2011. The evaluated crude properties were density, API

gravity, viscosity at 100°C where available, pour point, water content, salt content, TAN, sulfur content, and asphaltenes. The main product cuts were naphtha, kerosene, diesel, and atmospheric residue.

Table 1. Nile Blend crude-property dataset used for crude quality drift analysis

Year	Density (kg/m ³)	API (°API)	Viscosity at 100°C (mm ² /s)	Pour point (°C)	Water (m%)	Salt (mgNaCl/L)	TAN (mgKOH/g)	Sulfur (wt%)	Asphaltenes (wt%)
2006.00	850.40	34.81	—	33.00	0.09	5	0.23	0.05	0.11
2007.00	864.80	32.04	—	33.00	0.75	—	0.4	0.07	0.05
2008.00	865.50	32.00	7.7	—	0.2	5.3	0.39	0.06	—
2009.00	867.50	31.60	7.58	33.00	0.5	8.06	0.59	0.04	—
2011.00	872.30	30.58	—	33.00	0.6	9	0.52	0.06	—

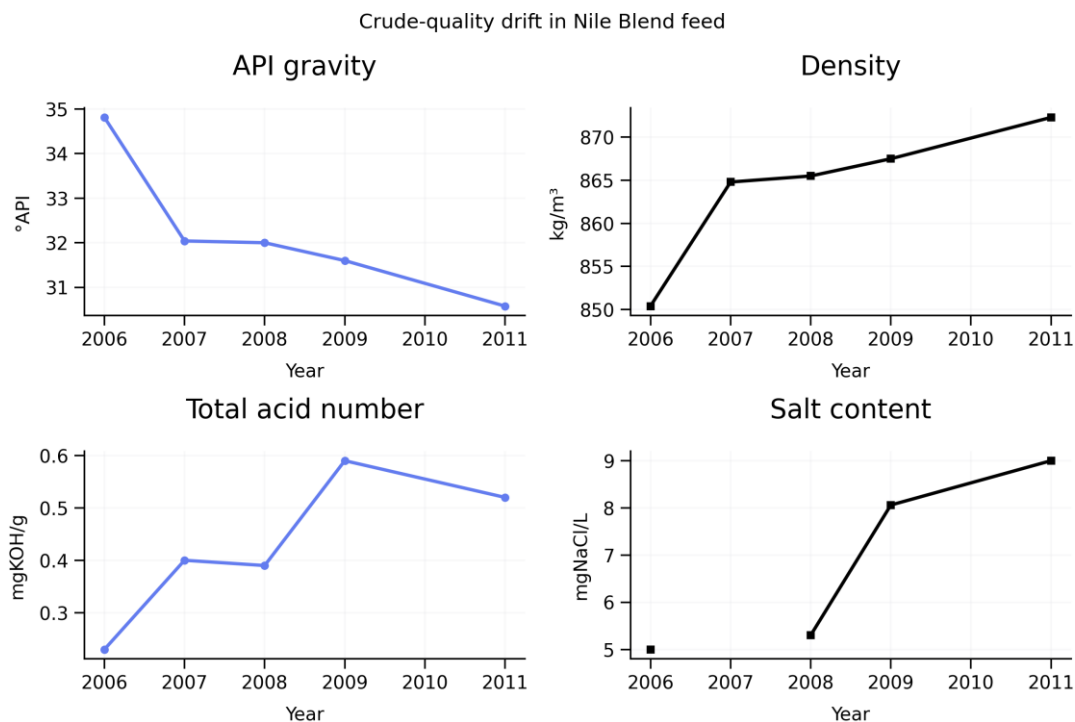


Figure 1. Nile Blend crude quality drift matrix showing changes in API gravity, density, TAN, and salt content

TBP distillation was used as the primary crude-characterization basis. TBP data define the boiling-range distribution and cumulative yield curve required to represent crude oil as pseudo-components in process simulation. The TBP basis is preferable to bulk gravity alone because crude oils with similar API gravity can have different volatility distributions, residue contents, and product-yield potential. Product-cut families

were interpreted according to refinery boiling-range practice for naphtha, kerosene, diesel, gas oil, and atmospheric residue. (Barman, B. N., Cebolla, V. L. & Membrado, L., 2000; Gautam, K., Jin, X. & Hansen, M., 1998; Durand, J. P., 2000; Eckert, E. & Vanek, T., 2005; Leelavanichkul, P., Deo, M. D. & Hanson, F. V., 2004; Nedelchev, A., Stratiev, D. & Ivanov, A., 2011; Chasib, K. F., 2011).

Aspen HYSYS V8.0 was used for steady-state process simulation. The Peng-Robinson equation of state was selected because it is widely applied for hydrocarbon vapor-liquid equilibrium in oil and gas and refinery systems. The crude assay was entered as TBP data with bulk properties, density and viscosity curves where available, and light-end information. Auto-blend cut generation was used to build the pseudo-component representation required for atmospheric distillation calculations. (Aspen Technology, 2004; 2005a; 2005b; 2005c; Matar, S. & Hatch, L. F., 2000; Buckley, P. S., Luyben, W. L. & Shunta, J. P., 1985; Casavant, T. E. & Cote, R. P., 2004; Denn, M. M., 2004).

The reference simulation included a crude preheat train, desalter, heaters, preflash separator, furnace, and atmospheric column. The reference column contained 29 stages, a partial condenser, three side strippers, three pumparounds, and bottom stripping steam. The feed to the preflash separator was approximately 103 kbpd at about 175°C and 540 kPa, followed by furnace heating to about 400°C before entry to the atmospheric column. The reference column top and bottom stage pressures were approximately

14 and 230 kPa, respectively, and bottom steam was introduced at 3400 kg/h.

The KRC configuration used for field interpretation is larger than the reference HYSYS teaching configuration. The KRC CDU contains 52 stages with a partial condenser, three side strippers, three pumparounds, and bottom steam. The feed enters near tray 4. The reported top and bottom pressures are approximately 15 and 160 kPa, respectively, and bottom steam enters tray 1 at 3300 kg/h, 400°C, and 400 kPa. The AGO, diesel, and kerosene side systems are supported by side stripping and pumparound heat-removal loops distributed across the column.

Model validation used two levels. First, HYSYS benchmark liquid-volume flows were compared with the implemented model. This checked whether the process model reproduced reference flowsheet behavior. Second, HYSYS product-yield predictions were compared with TBP-derived yields for naphtha, kerosene, diesel, and residue over five API cases. This second check is more meaningful for crude quality interpretation because it tests whether simulated yield patterns follow assay-derived separation potential.

Table 2. HYSYS benchmark validation of CDU product liquid-volume flows

Product	Reference liquid flow	Model liquid flow	Error (%)
Naphtha	150.00	150.00	1.40e-05
Kerosene	62.00	62.00	5.32e-05
Diesel	130.00	130.00	4.77e-05
Atmospheric gas oil	30.00	30.00	2.00e-05

Plant performance was evaluated by comparing KRC real mass-yield values with assay-derived ideal mass-yield values for 2007, 2008, 2009, and 2011. The difference was calculated as KRC yield minus assay potential. Negative values indicate plant shortfall relative to assay potential, while positive values indicate higher plant yield in the product pool. This comparison was used diagnostically rather than as a complete plant calibration, because fully reconciled heat and material balances were not available.

Operating-flexibility sensitivity analysis considered three levers: effective tray count, feed tray position, and reflux ratio. Tray-number sensitivity focused on changes between 29 and 49

stages for three API cases. Feed tray position was evaluated from tray 2 to tray 36. Reflux ratio was evaluated from 0.5 to 1.0. Naphtha and atmospheric residue were selected as the primary response variables because increasing light-product recovery and limiting bottom-of-the-barrel production are central CDU economic objectives.

3. Results

The crude quality data show a clear drift toward heavier Nile Blend behavior. API gravity decreased from 34.81°API in 2006 to 30.58°API in 2011, a decline of 4.23°API or 12.2%. Density increased from 850.4 to 872.3 kg/m³, a rise of 21.9 kg/m³ or 2.6%. Salt content increased from 5.0 to

9.0 mg NaCl/L between endpoint measurements, equivalent to an 80% increase. TAN increased from 0.23 mg KOH/g to a maximum of 0.59 mg KOH/g, indicating a higher corrosion-management burden even though sulfur remained low at 0.04-0.07 wt%.

The TBP product-yield record indicates that the crude quality shift was large enough to affect refinery planning. Naphtha varied from 6.63 to 13.27 vol%, a range of 6.64 percentage points. Kerosene varied by 3.82 percentage points, diesel by 4.15 percentage points, and atmospheric

residue by 8.89 percentage points. The highest atmospheric residue yield was 66.29 vol% in 2009. Such variability can alter downstream hydrotreating demand, storage utilization, blending availability, and residue-handling requirements. The 2011 naphtha yield of 13.27 vol% is not interpreted as a simple continuation of the preceding declining trend. It likely reflects a change in well mix or upstream blending strategy, or alternatively operational or measurement variability; therefore, the 2011 point should be treated cautiously when interpreting crude quality drift from Table 3.

Table 3. TBP-derived product-yield distribution for evaluated Nile Blend crude samples

Year	Naphtha (vol%)	Kerosene (vol%)	Diesel (vol%)	Atmospheric residue (vol%)
2006.00	11.30	10.40	20.90	57.40
2007.00	9.6	8.9	18.30	63.20
2008.00	6.63	7.98	19.15	65.29
2009.00	7.22	8.45	18.10	66.29
2011.00	13.27	6.58	22.25	57.90

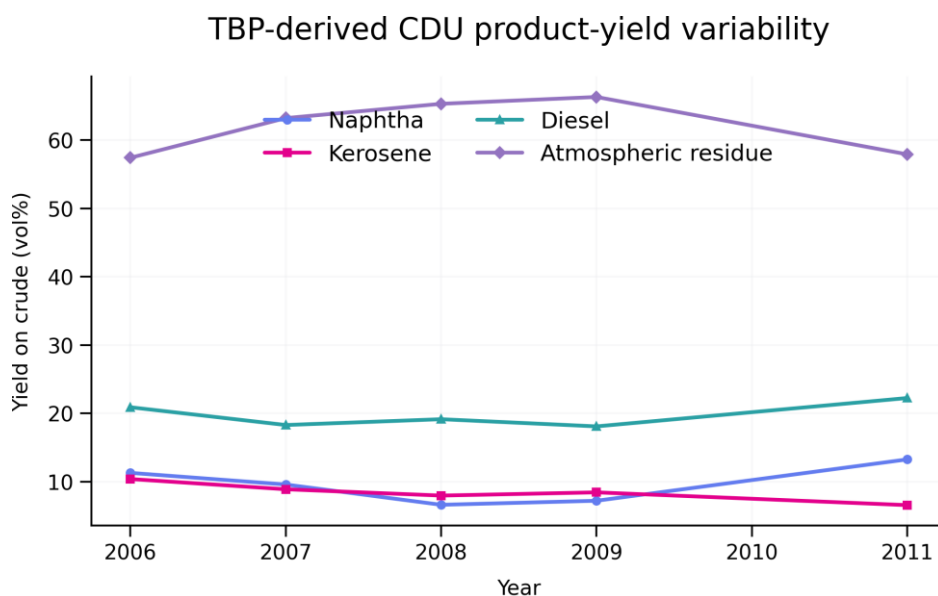


Figure 2. TBP-derived product-yield trends showing variability of light products and atmospheric residue with crude quality drift

HYSYS benchmark validation showed negligible numerical implementation error. The largest benchmark deviation was $5.32 \times 10^{-5}\%$ for kerosene. The HYSYS-TBP comparison gave a mean absolute difference of 0.39 vol%, RMSE of

0.74 vol%, and maximum absolute deviation of 2.80 vol% across four product cuts and five API cases. The largest difference occurred for residue at 30.58°API, where TBP gave 57.90 vol% and HYSYS gave 55.10 vol%. The agreement is

sufficiently strong for screening crude quality effects and ranking operating sensitivities. In Figure 3, the parity-plot deviations are small and randomly distributed rather than directional; the

maximum absolute deviation of 2.80 vol% indicates close prediction–measurement agreement with no clear systematic model bias.

Table 4. Summary validation metrics for the HYSYS model and HYSYS–TBP yield agreement

Metric	Value	Engineering meaning
Maximum HYSYS benchmark error	5.32e-05%	Numerically negligible implementation error
HYSYS-TBP MAE	0.39 vol%	Average cut-level model/assay difference
HYSYS-TBP RMSE	0.74 vol%	Overall model/assay scatter
Maximum HYSYS-TBP absolute deviation	2.80 vol%	Largest individual product-yield difference

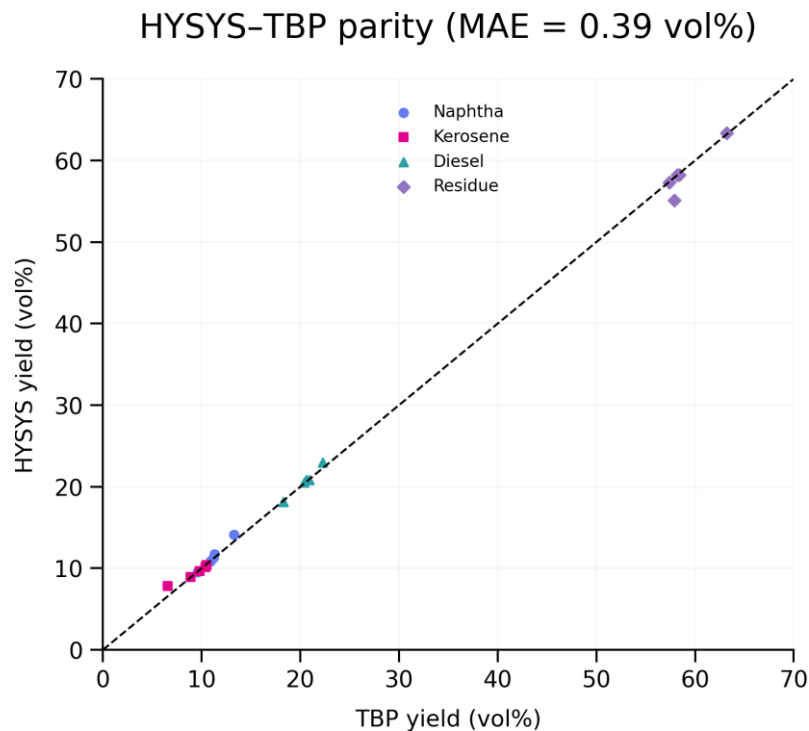


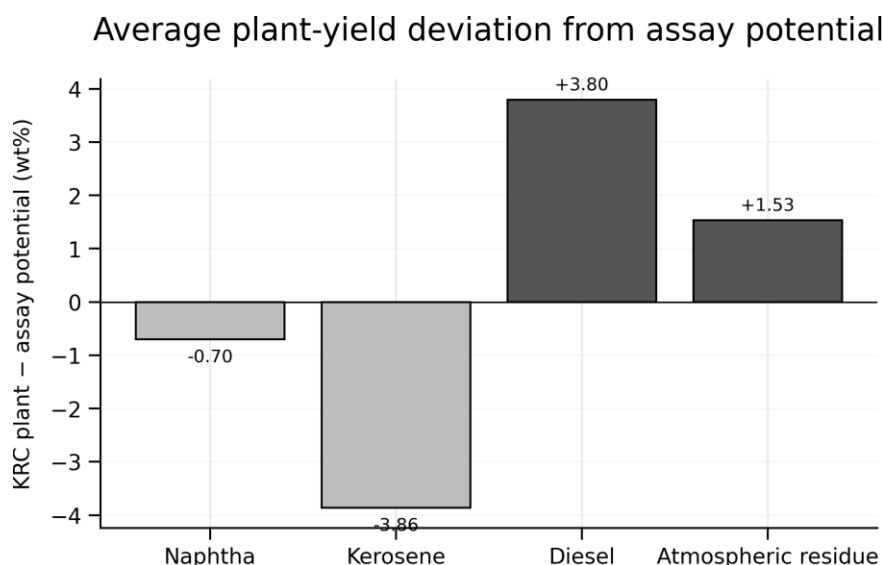
Figure 3. HYSYS–TBP parity plot for naphtha, kerosene, diesel, and atmospheric residue yields

Plant-yield comparison indicates that realized plant yields were shifted toward heavier products relative to assay potential. Average naphtha yield was 0.70 wt% below assay potential and average kerosene yield was 3.86 wt% below assay potential. Diesel yield was 3.80 wt% above assay potential and atmospheric residue was 1.53 wt% above assay potential. The

combined naphtha-plus-kerosene shortfall was 4.56 wt%, while the combined diesel-plus-residue excess was 5.33 wt%. This redistribution suggests recoverable operating losses, conservative cut-point control, product-quality protection, side-stripping limitations, or hydraulic/heat-transfer constraints.

Table 5. Average KRC plant-yield deviation relative to assay-derived ideal yield potential

Product	Average KRC plant minus assay potential (wt%)
Naphtha	-0.698
Kerosene	-3.86
Diesel	3.8
Atmospheric residue	1.53


Figure 4. Plant-yield deviation from assay potential showing light-product shortfall and heavier-product excess

Tray-number sensitivity showed that increasing effective stage count did not improve naphtha recovery under the tested operating setup. Across API 32.47, 33.91, and 34.30, increasing trays from 29 to 49 reduced naphtha by an average of 0.74 percentage points and increased atmospheric residue by 0.93 percentage points. The corresponding naphtha-production efficiency indices decreased from 96 to 92, 61 to 53, and 66 to 58 for the three API cases. These results do not justify an immediate tray-removal recommendation; rather, they show that stage count must be evaluated together with cut points, draw locations, reflux, heat-removal distribution, and hydraulic limits. Although the decrease in naphtha yield with increasing effective tray number is counter-intuitive, it can be explained by coupled changes in internal reflux distribution, column temperature profile, local vapor-liquid traffic, and effective volatility cuts; in the simulated setup, additional stages sharpened fractionation in a way that shifted

recoverable light material away from the naphtha draw rather than simply increasing naphtha recovery.

Feed tray position produced the largest modeled response. Moving the feed from tray 2 to tray 36 increased naphtha from 11.4 to 26.7 vol%, a gain of 15.3 percentage points, and reduced atmospheric residue from 58.9 to 43.6 vol%, a reduction of 15.3 percentage points. The magnitude of this result should be validated by plant tests, but the direction is physically consistent: feed entry elevation changes the available rectifying and stripping sections and therefore changes the distribution of vaporized light components.

Reflux ratio was a practical operating lever but involved a yield-quality tradeoff. Increasing reflux from 0.5 to 1.0 reduced naphtha from 14.0 to 9.9 vol%, a loss of 4.1 percentage points, and increased atmospheric residue from 57.0 to 61.0 vol%, a gain of 4.0 percentage points. Lower reflux can recover light-product volume, but final

operation must satisfy naphtha and kerosene blending constraints. endpoint, vapor-pressure, flash-point, and

Table 6. Operating-flexibility sensitivity summary for naphtha recovery and atmospheric residue control

Lever	Naphtha response		Residue response		Interpretation
Effective trays: 29 to 49	-0.74	percentage points (average)	+0.93	percentage points (average)	Stages alone did not recover light yield in the tested setup
Feed tray: 2 to 36	+15.3	percentage points	-15.3	percentage points	Strongest modeled flexibility lever
Reflux ratio: 0.5 to 1.0	-4.1	percentage points	+4.0	percentage points	Accessible but constrained by product quality

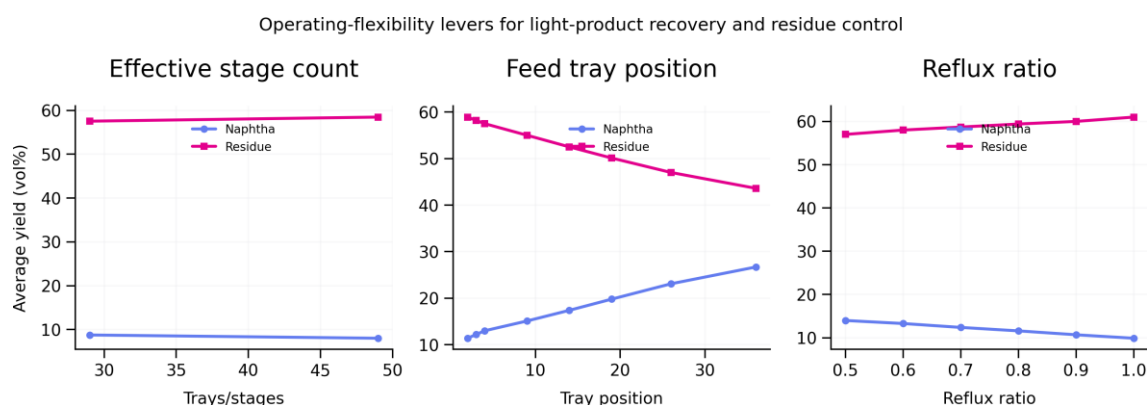


Figure 5. Sensitivity of naphtha and atmospheric residue to effective tray count, feed tray location, and reflux ratio

4. Discussion

The evidence shows that Nile Blend crude quality drift is not a minor laboratory trend; it has measurable implications for refinery product allocation. The API decline and density rise indicate a heavier feed, but the product-yield data also show that API alone is not sufficient to predict the product slate. The 2011 sample had the lowest API gravity but did not produce the maximum atmospheric residue yield in the TBP data. This means that TBP curve shape and cut-specific composition remain essential for CDU prediction. API gravity should therefore be used as a surveillance flag, not as a substitute for assay-based modeling.

The plant-yield deviation is one of the most valuable diagnostic results. The HYSYS and TBP results describe the separation potential under idealized or assay-consistent conditions, while the KRC data describe what the operating unit

actually delivered. The systematic deficit in naphtha and kerosene and excess in diesel and residue indicates that part of the light-product potential may be shifted into heavier cuts. Potential causes include conservative cut-point operation, side-stripper underperformance, insufficient stripping steam, pumparound heat-removal imbalance, feed-condition deviation, tray efficiency loss, fouling, entrainment, or product-quality constraints that intentionally bias the operation toward heavier products.

The tray number result requires careful scientific interpretation. More stages can improve theoretical separation, but the objective of a CDU is not theoretical separation alone. A column can become sharper yet still produce less naphtha if draw locations, condenser duty, reflux, product cut points, and heat-removal distribution are not optimized simultaneously. Therefore, the tray number sensitivity should be read as a warning against isolated hardware thinking. Any retrofit

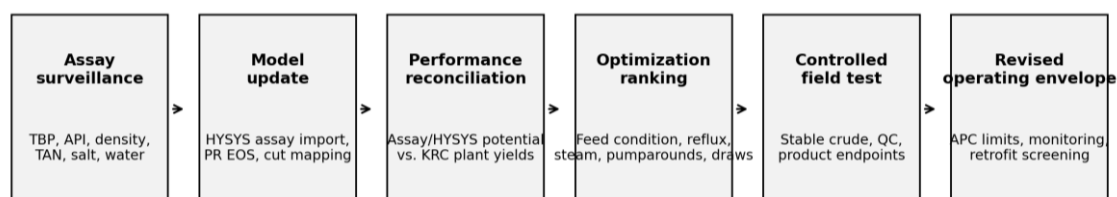
involving trays must be preceded by hydraulic rating, pressure-drop review, tray-efficiency calibration, product-quality analysis, and economic optimization. (Popoola, L. T., Adeniran, J. A. & Aderemi, B. O., 2012; RWTUV, 2005).

The feed entry sensitivity is technically important because it points toward a broader operating concept: the effective location and state of the feed determine how much vapor and liquid traffic enters the rectifying and stripping sections. Physical feed nozzle relocation may be difficult in an existing plant, but refinery engineers can still influence the effective feed state through furnace outlet temperature, preflash vapor fraction, feed enthalpy, and potentially split-feed routing. For new or revamped units, multiple feed nozzles or flexible feed routing could provide resilience against crude quality drift.

The reflux-ratio result is operationally accessible but must be constrained by product quality. A lower reflux ratio can increase naphtha volume in the model, but insufficient reflux may increase

endpoint overlap and off-spec risk. Conversely, high reflux may protect separation sharpness but reduce light-product withdrawal and increase energy use. The optimum reflux should therefore be selected using a multi-objective function that includes product values, quality constraints, energy cost, column hydraulic limits, and downstream blending requirements rather than yield volume alone.

The final engineering contribution is a closed-loop CDU surveillance workflow. Crude assays should trigger model updates; model outputs should be compared with plant yields; deviations should be diagnosed by product cut and operating variable; and candidate changes should be ranked before plant testing. This workflow transforms crude quality drift from an observation into a manageable operating problem. It also provides a communication bridge between upstream crude-slate management and downstream refinery performance.



Closed-loop CDU management converts crude-quality drift into verified operating actions before major hardware changes.

Figure 6. Recommended closed-loop CDU surveillance and optimization workflow for managing crude quality drift

Important uncertainties remain. The simulation is steady state and does not fully represent tray efficiency, fouling, entrainment, flooding margin, heat losses, control-system behavior, analyzer uncertainty, or product-quality specifications. Several historical crude properties are incomplete. Plant comparisons are based on available yield data rather than fully reconciled heat and material balances. Therefore, the results should guide engineering screening and plant-test planning rather than serve as final operating instructions. Stronger validation should include product endpoint data, draw temperatures, column pressure-drop trends, pumparound duties, side-stripper steam rates, online analyzer readings, and stable-crude test runs. Historical

refining innovation and refinery complexity context also support cautious interpretation of design flexibility and retrofit decisions (Enos, J. L., 1962; de Klerk, A., 2008; Energy and Environmental Analysis, Inc., 2011).

5. Conclusions

(1) Nile Blend crude quality drift was quantitatively significant. API gravity declined by 4.23°API and density increased by 21.9 kg/m³ between 2006 and 2011, while salt and TAN trends indicated increased operating surveillance needs.

(2) CDU product-yield variability was material. Naphtha varied by 6.64 percentage points and atmospheric residue by 8.89 percentage points,

which is large enough to affect downstream processing, storage, and blending strategy.

(3) The HYSYS model was adequate for screening and sensitivity ranking. Benchmark error was below $5.32 \times 10^{-5}\%$, and HYSYS–TBP agreement was strong with MAE = 0.39 vol% and RMSE = 0.74 vol%.

(4) Plant-yield comparison showed a combined naphtha-plus-kerosene shortfall of 4.56 wt% relative to assay potential and a combined diesel-plus-residue excess of 5.33 wt%, indicating a shift toward heavier product pools under actual operating conditions.

(5) Feed-entry strategy was the strongest modeled flexibility lever, changing naphtha and residue by 15.3 and 15.3 percentage points, respectively, across the evaluated feed-tray range.

(6) Reflux ratio was a practical but constrained operating lever: increasing reflux from 0.5 to 1.0 reduced naphtha by 4.1 percentage points and increased residue by 4.0 percentage points.

(7) Effective CDU optimization under crude quality drift requires simultaneous consideration of crude assay, feed condition, reflux, draw strategy, pumparound heat removal, side stripping, product specifications, and hydraulic limits.

6. Recommendations and Field Application Implications

Implement assay-driven CDU surveillance. Refinery operation should maintain a routine assay update cycle that includes TBP distribution, API gravity, density, TAN, salt, water content, sulfur content, and key product endpoints. Each material crude quality change should trigger a model refresh and an updated operating-envelope review.

Use reconciled plant-yield diagnostics. Product yields should be compared against assay and HYSYS potential on a regular basis. Persistent naphtha or kerosene shortfalls should trigger review of cut points, side stripping, pumparound duties, draw temperatures, column pressure drop, and furnace/preflash conditions.

Prioritize reversible operating changes before hardware retrofit. Reflux, stripping steam, furnace outlet temperature, product draws, pumparound duty, and preflash operation should be optimized before any modification to internals or feed nozzles is considered.

Evaluate feed-condition flexibility. If plant tests confirm the modeled sensitivity to feed tray position, future revamps should assess additional feed nozzles, flexible routing, split-feed capability, and heat-exchanger-network flexibility. Existing units may still benefit from changing effective feed state through preflash vapor fraction and feed enthalpy control.

Develop a calibrated CDU digital model. A high-confidence model should include tray efficiency, hydraulic constraints, pressure-drop calibration, heat losses, product-quality constraints, and economic objective functions. The optimization target should be net refinery value and specification compliance, not maximum naphtha volume alone.

Conduct controlled plant tests. Any major operating-window change should be tested under stable crude feed with reconciled mass and energy balances, laboratory product endpoint measurements, and recorded side-stream and pumparound data.

7. Limitations and Validation Needs

- 1) The simulation is steady state and does not capture all dynamic control responses, fouling, entrainment, flooding margin, exchanger degradation, or full product-quality constraints.
- 2) Some historical assay properties are incomplete, especially viscosity, salt, and asphaltenes for selected years.
- 3) Plant-yield comparison is diagnostic and should be strengthened by reconciled heat and material balances and controlled test runs.
- 4) The feed-tray sensitivity indicates strong design leverage but does not automatically imply that physical feed-nozzle relocation is feasible in the existing plant.
- 5) Economic optimization requires market prices, product specifications, energy costs, and downstream unit constraints that are not fully represented in the available dataset.

Abbreviations

AGO	Atmospheric Gas Oil
API	American Petroleum Institute Gravity
CDU	Crude Distillation Unit

AGO	Atmospheric Gas Oil
EOS	Equation of State
HYSYS	Aspen HYSYS Process-simulation Platform
KRC	Khartoum Refinery Company
MAE	Mean Absolute Error
PR	Peng-Robinson
RMSE	Root Mean Square Error
TAN	Total Acid Number
TBP	True Boiling Point
vol%	Volume Percent
wt%	Mass Percent

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Author Contributions

Mohamed Omer Mohamed Elnaeem: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing - review and editing.

Data Availability Statement

The numerical data supporting this manuscript are reported in the tables and figures, including crude assay properties, TBP product yields, HYSYS validation results, operating sensitivity endpoints, and KRC plant-yield comparisons. Additional high-frequency operating data, product quality records, and reconciled plant balances may be subject to refinery confidentiality and should be requested from the operating organization where permitted.

Conflicts of Interest

The authors declare no conflicts of interest.

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