Digital twin optimises FCC operations for real separator behaviour

Digital twins based on process simulation models are invaluable for overcoming limitations in the design or operations phases to optimise plant profitability

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Separation processes play a crucial role in the oil and gas upstream, midstream, and downstream sectors. For example, in refineries, the overhead vessels and the crude distillation and vacuum distillation units separate hydrocarbon reflux from sour water and overhead vapours. In many cases, excessive liquid carry-over influences product quality or yield. To assure appropriate product yields, treatment and conversion units employ two- and three-phase separation processes critical to proper operation of such units.

Other important separators include the compressor suction scrubbers or knock-out (K.O.) drums. The proper design of these devices is necessary to ensure the operational integrity of the compressors. Common concerns include excessive carry-over and large droplet size in the suction gas. Often, droplet size criteria are met while the flow rate of liquid carry-over is excessive or vice versa.

In most oil companies and engineering, procurement and construction (EPC) contractors, separation expertise is either limited or absent. Therefore, in the design phase of new facilities, oil companies and EPC contractors rely heavily on vendors for vessel sizing and/or vessel performance estimates. Additionally, the industry traditionally lacks unified separation vessel design practices. As a result, the design and sizing of vessels rely on various traditional in-house standards, rules-of-thumb, and disparate 'spreadsheet tools'. Frequently, in-house tools provide criteria based sizing of vessels and internals, but cannot predict carry-over performance. This means engineers can produce designs without appreciating the extent to which the separation equipment will fulfil its purpose. On the one hand, vessels may be oversized. On the other hand, they may have insufficient capacity to handle off-design conditions or process upgrades.

Software tools

Due to the complexity of many oil and gas process operations, insightful engineering teams are keenly aware that an appropriate digital twin is vital to achieving key business objectives, including:

- Improve profitability with assured ROI by increasing operating margins while reducing expenses
- Better facility management, production planning, and decision making from a holistic view of facility performance
- Meet and enhance unit production targets through continuous process unit monitoring
- Identify system bottlenecks and major operational risks
- Devise possible debottlenecking strategies with corrective actions

Process simulation provides a powerful platform for designing, monitoring, and optimising refinery and petrochemical operations. Recent developments in simulation technology have improved the accuracy and user-friendliness of these tools. The Petro-SIM process simulator is well suited to building digital twins because it provides meaningful data regarding the efficiency and effectiveness of plant operations at an asset level.

In addition, MySep software is adept at simulating the performance of separation equipment. For design, the software guides engineers to follow sound practices to assure performance. For evaluating existing equipment, it brings to bear proprietary incremental modelling to predictions of carry-over. KBC and MySep have partnered to combine the strength of Petro-SIM's process simulation with MySep's rigorous separator modelling. The combination of these tools help operators mitigate risks and optimise operations to ensure the following:

- **Efficiency**: They provide a complete detailed representation of the plant to assess the interactions between various units and asset groups
- **Accuracy**: They use rigorous thermodynamic packages and research-validated ratings. The model predictions can be used with confidence, even when extrapolating them to new conditions and feedstocks
- **Better decision-making**: Petro-SIM's time series function enables process engineers to run a series of steady-state simulations and observe the long-term impact on operations
- **Cost savings**: Engineering, operations, training, planning, and capital improvement projects use one model. All key stakeholders use the same technology to streamline work processes

Case study

In a refinery FCC unit, reactor products enter the main fractionation column (MFC). The side stripper on the MFC produces heavy naphtha and light cycle oil. Then, light gas-

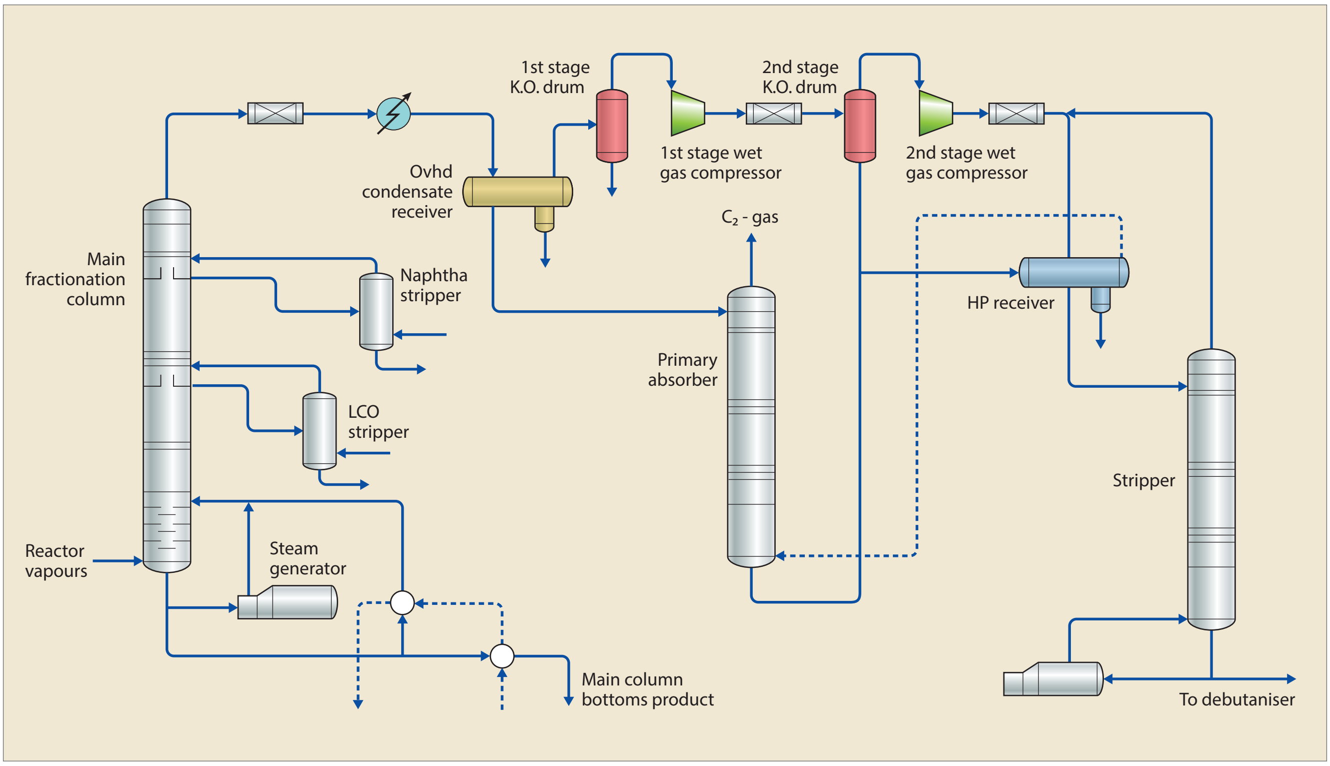

Figure 1 Flow diagram of the MFC and GCU systems

oline and light hydrocarbons in the MFC overhead stream are routed to the gas concentration unit (GCU). Due to the low pressure of the MFC, the overhead stream produces gas that contains a significant concentration of heavy hydrocarbons, whilst the overhead liquid product contains light hydrocarbons. The resulting vapour stream is sent to the GCU with a wet gas compressor for high-pressure recontacting and separation.

Poor separator design and inappropriate selection of internals can cause excessive liquid carry-over. This liquid carry-over propagates through the process, affecting downstream equipment. Ultimately, it can lead to progressive degrading of compressor performance and premature machine failure. Unplanned shutdowns due to equipment failures are associated with significant revenue losses. Shutdown of an FCC unit may incur operational losses of up to $1.5 million per day. Loss-risk of such a magnitude can be mitigated with a moderate investment in a high-fidelity digital twin capable of simulating all key equipment.

Vessel geometry and specifications

Separator	Configuration	Nozzles	Internals
MF condensate receiver	Vessel orientation: Horizontal Separation type: 3-phase with boot Vessel ID: 3962mm Vessel T-T length: 11888mm Boot ID: 1524mm Boot height: 2362mm	Inlet: 32in Gas outlet: 24in HC liquid outlet: 20in Water outlet: 3in	Vane type for inlet device No demisting device
1st stage compressor K.O. drum	Vessel orientation: Vertical Separation type: 2-phase Vessel ID: 2515mm Vessel T-T length: 5029mm	Inlet: 24in Gas outlet: 24in Liquid outlet: 2in	Half pipe for inlet device No demisting device
2nd stage compressor K.O. drum	Vessel orientation: Vertical Separation type: 2-phase Vessel ID: 1575mm Vessel T-T length: 4750mm	Inlet: 12in Gas outlet: 12in Liquid outlet: 4in	Half pipe for inlet device Mesh pad demisting device
HP receiver	Vessel orientation: Horizontal Separation type: 3-phase with boot Vessel ID: 2210mm Vessel T-T length: 8840mm Boot ID: 686mm Boot height: 1219mm	Inlet: 10in Gas outlet: 8in HC liquid outlet: 10in Water outlet: 2in	Vane type for inlet device No demisting device

Table 1

Figure 1 presents a basic flow diagram of the MFC and GCU systems in the FCC unit. Gas from the GCU is compressed and combined with primary absorber bottoms and stripper overhead gas. This combined stream is then cooled and sent to the high-pressure receiver. Gas from this separator is routed to the primary absorber.

Based on economic analysis and production planning, the operator modified the production targets of the FCC unit. The plan included an increase of the throughput by 15% (Case A), which is 5% above the design capacity. Additionally, more propane and light product would be produced, reflecting a weakening market for naphtha whilst the market for petrochemicals was seen to be strengthening. The strategy involved increasing the ZSM-5 catalyst addition to the existing inventory (Case B) and increasing the riser outlet temperature to 540ºC (1004ºF) to increase conversion (Case C). Rating calculations were required for all equipment, including separators around the MFC.

This case study investigated the performance of the following four separators in the FCC unit:

1. The condensate receiver of the main fractionation tower

2. Two compressor K.O. drums in the gas plant

3. The high-pressure separator

To accommodate the increase in gas production from the MFC, the operator added a third compression train, identical in size and capacity to the two existing ones.

This case study was conducted to determine the adequacy of the existing equipment, particularly the overhead condensate receiver, both compressor suction K.O. drums, and the HP separator. A key operational requirement involved limiting both the maximum droplet size and excessive volume of entrained liquid. These efforts helped prevent cumulative damage to costly rotating equipment and minimised the risk of an unplanned shutdown.

Outline specifications of the four vessels under investigation are presented in **Table 1. Figure 2** illustrates the configuration of the original MF condensate receiver vessel.

Petro-SIM process simulator, MySep Studio, and MySep Engine were used to investigate the performance of these four vessels. The simulation results are presented in **Tables 2-5**.

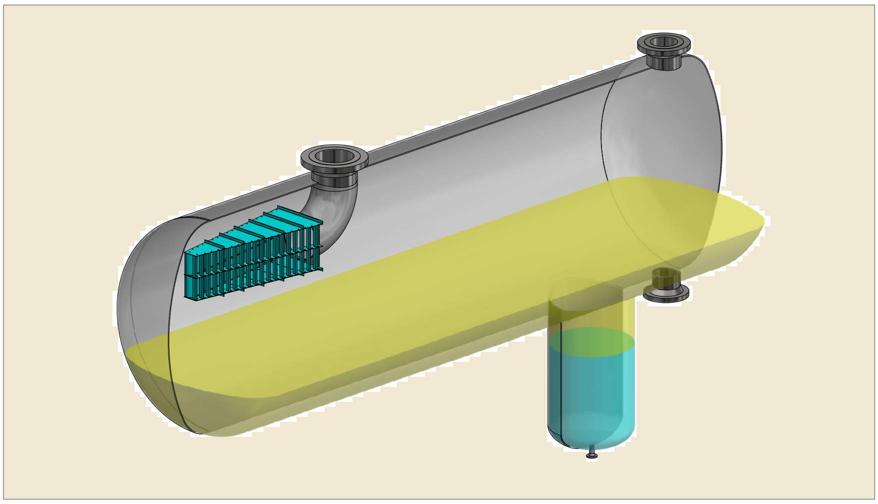

Figure 2 MF condensate receiver original configuration

Simulation results for the MFC overhead condensate receiver

	Feed rate increment,%	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, μm
Case A	+ 15	2.1-0.31	92.3-204	107
Case B	+ 27	3.2-0.47	1944-4285	137
Case C	+ 29	3.5-0.50	2719-5994	142

Table 2

Simulation results for the first-stage compressor K.O. drum

	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, μm
Case A	0.23-0.03	---	216
Case B	0.45-0.07	11.0-24.2	299
Case C	0.49-0.07	20.1-44.4	310

Table 3

Simulation results for the second-stage compressor K.O. drum

	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, μm
Case A	0.99-0.14	---	15
Case B	1.5-0.22	0.08-0.17	14
Case C	1.8-0.27	0.17-0.36	13

Table 4

Simulation results for the HP receiver

	Feed rate increment, %	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, μm
Case A	+ 15	2.5-0.36	0.63-1.4	33
Case B	- 4	2.5-0.36	5.9-13.0	38
Case C	+ 9	3.4-0.49	44.1-97.2	41

Table 5

It is intended that liquid carry-over from the MFC overhead condensate receiver be captured by the first-stage K.O. drum. The higher volumetric flow rates for cases B and C result in higher mist flow rates and small droplets entering the MFC overhead condensate receiver. Analysing the flow regimes reveals annular mist flow in both horizontal and vertical pipes. In addition, the first-stage K.O. drum has insufficient capacity to handle the excessive mist load. It was therefore concluded that the condensate receiver would require retrofitting with a demisting device. This would avoid any problems associated with excess liquid in flare gas and capture useful product.

A droplet size of 100 μm entering a compressor is considered excessive. Moreover, the predicted volume of entrained liquid would damage the process compressors. **Figure 3** shows the volume frequency distribution of the mist flow in the inlet and gas outlet streams for the MFC overhead receiver, showing all three cases. Although the separator removes all droplets of 150 μm and larger for all cases, the predictions reveal significantly higher carry-over in the gas outlet

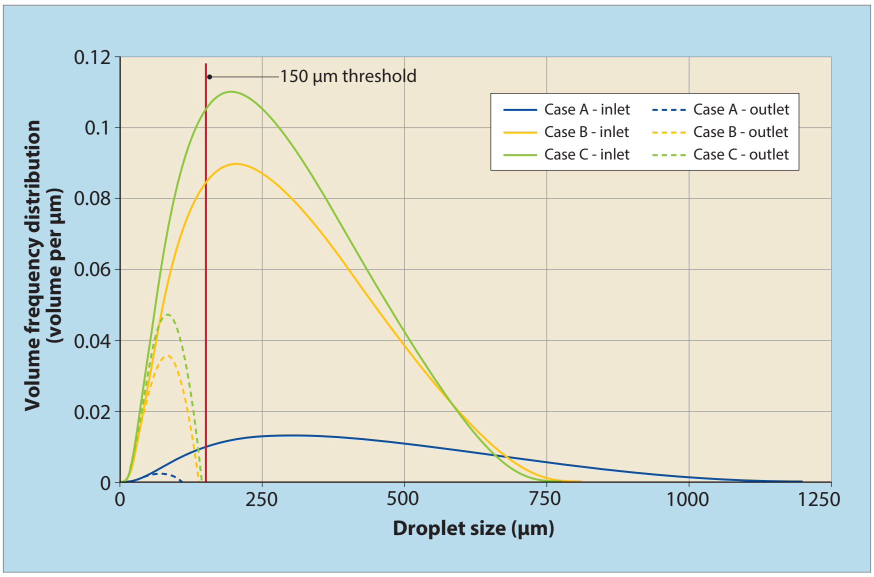

Figure 3 Droplet size distribution for inlet and gas outlet

Retrofitted designs	
Separator	**Internals**
MF condensate receiver	Vane type for inlet device and a vane pack vertical demisting device
First-stage compressor KOD	Vane type inlet device a horizontal mesh agglomerator and a mesh pad demisting device
Second-stage compressor KOD	Vane type inlet device, a horizontal mesh agglomerator and a mesh pad demisting device

Table 6

stream for Cases B and C. The first-stage compressor K.O. drum cannot handle this higher mist load, which would result in the compressor receiving a serious excess of liquid.

MySep Studio provides appropriate detailed analysis of the range of possibilities. It is clear that quantities of entrained liquid for both first and second stages would be damaging and compromise sustained compressor operation. Therefore, both K.O. drums required modifications. Finally, analysis demonstrates that liquid carry-over from the high-pressure (HP) receiver was modest and could readily be collected in the primary absorber for recycle back to the HP receiver. No modifications to this vessel were deemed necessary.

In this study, MySep Studio software provided a detailed performance analysis and good, practical guidance that resulted in an optimum retrofit strategy for the MFC condensate receiver and compressor K.O. drums. This achieved satisfactory separation efficiency. **Table 6** summarises recommended new internals configurations. **Figure 4** illustrates the MF condensate receiver, as an example of the retrofit internals devised to optimise system performance. **Tables 7-9** summarise performance simulation results for the new internals configurations. It shows that the proposed retrofit designs eliminate significant liquid carry-over to compression stages.

The ability of MySep Studio to accurately predict separator performance allows operators to anticipate and prevent costly shutdowns. As part of a process, combining the digital twin with Petro-SIM technology and MySep Engine models allows speedy examination of alternative feedstocks or product slates to improve operations on an ongoing basis.

MySep Studio is an established process engineering tool for the design, evaluation, and simulation of two- and three-phase separators. Petro-SIM software offers system-wide process simulator and optimisation technology for asset design, performance optimisation, and digital twin surveillance. The combination of MySep Engine with Petro-SIM technology brings higher fidelity modelling to operational support engineers. These simulations accurately report the impact of liquid carry-over.

Conclusion

Refineries can avoid operational disruption and reduce financial losses attributed to inadequate process separators. When process engineers have specialist modelling tools available, they can quickly identify the best techno-economic solutions. From sandface to topside facilities, Petro-SIM digital twins

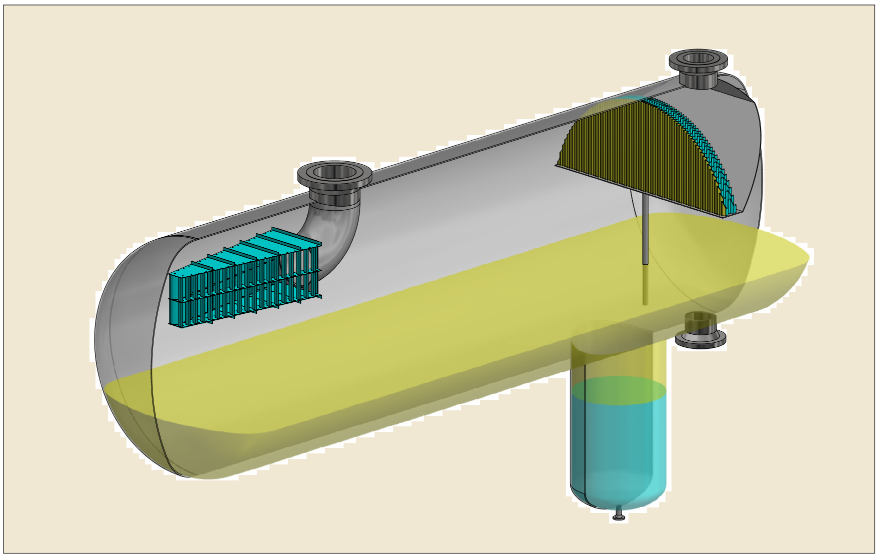

Figure 4 MF condensate receiver after retrofit

enhanced with MySep modelling uncover the constraints and physical dependencies across the entire supply chain. Digital twins based on process simulation models are invaluable for overcoming these limitations seamlessly in the design or operations phases to optimise plant profitability.

Rodolfo Tellez-Schmill is PetroSIM Product Manager with KBC Advanced Technologies. He has over 20 years of experience in chemical engineering activities including process engineering, quality control, project management, research and development, technical support and training, with a strong background in process simulation, control, optimisation, and design. He holds a PhD in chemical engineering from the University of Calgary, and is a Professional Engineer registered in the Province of Alberta, Canada.

Thomas Ralston leads MySep Pte Ltd's business development for digital process engineering. With over 30 years of process engineering software experience, he has been key to shaping MySep's product development and go-to-market strategies. His career has encompassed process engineering research, consultancy, management of software development and software product management.

Simulation results for the MFC overhead condensate receiver

	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, µm
Case A	2.2-0.32	9.5-21.0	53
Case B	3.4-0.50	99.5-219	46
Case C	3.7-0.53	127-280	45

Table 7

Simulation results for the first-stage compressor K.O. drum

	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, µm
Case B	0.63-0.09	----	9
Case C	0.70-0.10	----	9

Table 8

Simulation results for the second-stage compressor K.O. drum

	Pressure drop, kPa-psi	Liquid carry-over, kg/h-lb/h	Droplet size, µm
Case B	1.6-0.23	----	13
Case C	1.9-0.28	0.06-0.13	12

Table 9

Wim Moyson supports MySep Pte Ltd's commecial, training and process design support activities as consultant. He has over 23 years of experience in the phase separation industry and holds a MSc of Industrial Sciences degree in chemical engineering from the Hogeschool Antwerpen in Belgium.