

DIVIDING WALL COLUMN REVAMP OPTIMISES MIXED XYLENES PRODUCTION

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The successful revamp of a conventional tray Xylenes Distillation Column (3800 mm/4300 mm diameter) is described. The column takes a xylene side-stream from reformate to feed an aromatics plant to make higher value products. Changing the column configuration to a Dividing Wall Column (DWC) resulted in improved product purity and significant energy savings. The project cycle is detailed including process design, hydraulic design, mechanical design, manufacture, testing and site work. Economic benefits are outlined and the lessons learned are discussed.

KEYWORDS: Distillation, Xylene, Dividing Wall, Energy Saving

INTRODUCTION

ExxonMobil Fawley Refinery near Southampton in the south of England operates a distillation column (Figure 1) to recover mixed xylenes from reformate motor gasoline. The recovered mixed xylenes product is sent to an aromatics unit as feedstock for more valuable products. ExxonMobil has many ongoing projects to improve energy efficiency worldwide through technology development and implementation. The deployment of Dividing Wall Column (DWC) technology for the revamp of the Fawley xylenes column was identified as a good opportunity to achieve significant energy savings and improved product purity.

DWC TECHNOLOGY

The concept of the DWC dates back to the 1940s and has been the subject of many papers. The first U.S. patent describing use of a vertical wall in a side-stream fractionation column, used to improve both the front end and back end fractionation of the side-stream, was by R. O. Wright.¹ Mr. Wright was an employee of the Standard Oil Development Company, a forerunner of the ExxonMobil Research and Engineering Company. The principles of the DWC will not be restated here but are well explained in the literature.^{2,3,4,5,6,7}

DWC technology has been applied by European companies for the last 45 years. There are now approximately 70 towers in operation around the world, with the largest tower measuring several meters in diameter. Many of these towers use mass transfer equipment supplied by Koch-Glitsch. Until recently there has been relatively little commercial application of the full DWC concept at ExxonMobil.⁸ However, there were



Figure 1. Xylene column at ExxonMobil Fawley refinery

applications of a partial dividing wall. For example, within ExxonMobil, internal vessel partitions have been used to segregate feeds for different disposition of bottoms products.⁹ There was also a single instance of an internal side rectifier installed in an ExxonMobil linear paraffin unit tower. But within ExxonMobil there was no full DWC in operation until the Fawley xylenes tower application. Therefore, consistent with company procedures, the DWC technology went through a rigorous technical evaluation and risk mitigation before its implementation.

There is additional complexity involved in the design of a DWC. There are many more degrees of freedom available to the designer of a DWC compared to a conventional distillation train, which makes optimisation difficult and time consuming. A further restraint has been the perceived complexity and uncertainty of the control system. However, with the relatively cheap availability of computers and simulation packages, the design is far less daunting. In addition, the issues with the control system have been mitigated by modern computerised control systems.

The time available for revamp work might be one reason for avoiding a DWC. But as pointed out later in this paper, significant advances in this area have been made. So it is expected that more applications will occur especially as the value of energy conservation projects increase. The authors estimate that the design process is an order of magnitude

more complex than a conventional route, but this is negligible when compared to the 30% savings in energy and also in reduced capital costs for a new plant.

PROCESS DESIGN

The existing column configuration (Figure 2) was a conventional column with 51 valve trays. The feed was liquid phase to tray #38. The mixed xylenes product was taken as a

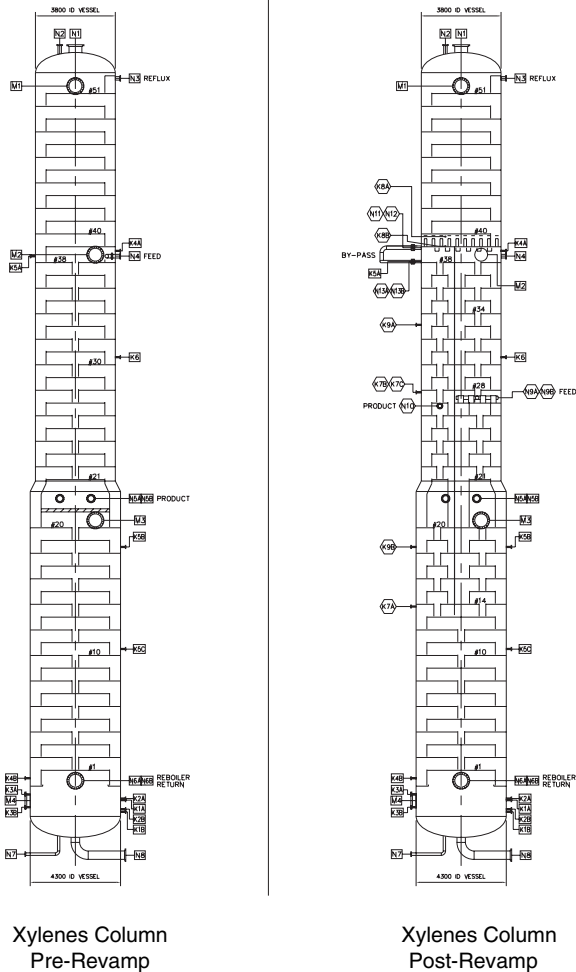


Figure 2. Xylenes column pre-revamp xylenes column post-revamp

vapour side draw above tray 20. Above this elevation, because of the decreased vapour traffic, the column diameter was swaged down from 4300 mm to 3800 mm inside diameter. The column had an air-cooled condenser and a horizontal thermosyphon reboiler (33 barg steam). The xylene product was also cooled by an air-cooler.

The existing column performance was modelled to provide a basis for the DWC modelling and to establish accurate tray efficiencies for use in the DWC design. The modelling tool used was Provision.

Because the column size was fixed and it was desired to minimise the complexity of the revamp the total number of trays and, therefore, the number of theoretical stages were also fixed. Further, it was desired to re-use the existing reboiler and condenser. These constraints limited the number of degrees of freedom available, which simplified the process design. The choices to be made were the number of trays above the Dividing Wall (DW), the number of trays below the DW and the location of feed and product draw. The number of trays above and below the feed on the prefractionation side of the DW and the draw on the product side of the DW were determined by the locations of the feed and product draw, respectively. Finally, the liquid split at the top of the wall and the vapour split at the bottom of the wall had to be selected to set the L/V ratio in each section.

Initially the design did not look as though it could be achieved within the given constraints. However, it was determined that the xylenes product could be taken in the liquid phase, which reduced the vapour traffic and allowed a practical design. This also reduced the requirement for cooling the product.

Economics dictate the optimum degree of desired xylenes recovery, which leads to a wide range of operating conditions for the column. Two quite different design cases and all of the conditions in between had to be considered.

In addition to the design case simulations, a number of sensitivity studies were required. The effects of heat transfer and leakage across the wall had to be considered. The former to determine if insulation of the wall was required, and the latter to determine the degree of seal required for the wall. The effect of errors in the estimated tray efficiency had to be determined. The tray bubble area shape is unusual and it was not clear that the empirical methods used by ExxonMobil would therefore accurately predict the efficiency. And finally and most importantly, the effect of the liquid and vapour splits had to be studied. From these studies, it was determined that (1) insulation was not required, (2) the seal of the wall was most critical around the feed and product draw, (3) it would be necessary to vary the liquid split at the top of the wall to operate the column at all desired conditions, and (4) reasonable errors in the assumed tray efficiency will not jeopardize performance.

One finding that was critical to both the process design and the hardware design and the final risk assessment of the technology was that errors in predicting the vapour split could be substantially corrected by changing the liquid split. Even though the tower was being designed with sieve trays, which have over 6,900 pressure drop data points available to members of Fractionation Research, Inc., there are still issues regarding the prediction of pressure drop. In the DWC, the pressure drop prediction is even more critical than a normal tower, because the vapour split is determined so that the differential

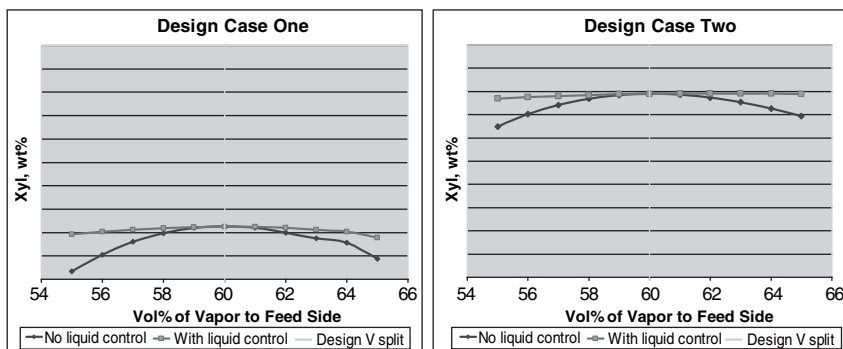


Figure 3. Product purity sensitivity to vapor split with and without liquid split control

pressure drop across the wall section is zero. Simulation work was done to investigate the effect of arbitrary errors in the vapour split, with control of the liquid split and without control of the liquid split. The results (Figure 3) show that control of the liquid at the top of the wall enables correction of any vapour split error.

The revamp column configuration (Figure 2) was a DWC with 51 trays. The DW ran from tray 14 up to tray 39. The feed was two phase to tray 27, which was also a chimney tray. The xylenes product was taken as a liquid side draw from tray 28, which was an active tray. A liquid splitter tray was installed at tray 39. The column condenser and reboiler did not require any modifications. The product cooler was also re-used without modification although it is now rather oversized.

The key parameters of the column performance before and after the revamp are listed in Table 1. They are compared to the Pre-DWC operation as percentages.

At case 1 operation the benefit is an energy saving of over 50%. Case 2 operation allows higher feed rate and product purity with an energy saving of over 25%. The fact that the DWC allowed to take a liquid phase xylenes product draw contributed to the energy savings.

Table 1. Operational parameters

Parameter	Pre-DWC	Case 1	Case 2
Operating Pressure	0.5 barg	0.5 barg	0.5 barg
Feedrate	100%	100%	103%
Xylenes Purity	100%	100%	106%
Xylenes Recovery	100%	100%	100%
Reboiler Steam	100%	47%	74%

HYDRAULIC DESIGN

The column was amply sized for the required duties both before and after the revamp, thus the hydraulic design was not challenging with respect to capacity. The trays were rated at ~80% of capacity (limited by jet flood) at the maximum loads. It was not necessary to use high capacity trays or reduced tray spacing to obtain more theoretical stages¹⁰. Due to the change from vapour to liquid product draw the column is now rather oversized below the swage.

The primary concern in the hydraulic design was the operability of the column. This meant that the trays had to operate efficiently over a reasonably wide range of conditions. To this end, different designs were optimised for each section of the column. Sieve trays were selected for because their pressure drop has been extensively studied and because capacity was not limiting.

It was important to get the correct vapour flow rate split on both sides of the DW. This was achieved by balancing the pressure drop through the DW section at the required flow rates on either side of the wall. Design features that are used to optimise this balance included offsetting the DW from the column centre line between the feed and product draw sides. This also helps balance the flood values on either side of the wall. The open area of the trays was varied in each section and weir blocks were used to avoid potential spray regime operation. The pressure drop was balanced very closely at the key design load. Inevitably at off-design conditions, the pressure drop balance will vary, which results in a change in the vapour split. At the other extreme of the design conditions, a shift in the vapour split was calculated. This was examined through a process simulation sensitivity study and found to be acceptable, provided that liquid split control is used to compensate.

The liquid split at the top of the wall is just as important as the vapour split. If a constant split is required, this can be achieved with a chimney tray to meter the liquid on either side of the wall in a fixed ratio. In this case, the process design required a variable split. One solution was to draw off all of the liquid and pump it back while controlling the flow to either side of the wall. This method requires a quite complicated and expensive system. To avoid this expense, a novel hybrid was developed using a chimney tray to meter the bulk of the liquid in a fixed proportion and a gravity fed external by-pass to control the liquid split as required. This novel arrangement was tested in a full-scale test rig at Koch-Glitsch's Kirkby Stephen works (Figure 4). The test not only validated the design and calibrated the by-pass but allowed several improvements to be made and future simplifications to the design.

The secondary concern in the hydraulic design was to make the revamp as simple as possible. The existing two-pass arrangement was retained re-using the existing down-comer chords. This meant virtually no modifications were needed for the existing tower attachments. The DW was designed perpendicular to the downcomers, which again meant no modifications to the existing tower attachments and that the orientations suited the existing nozzles and trays above and below the DW. The existing trays above and below the DW were checked for the new duties and reused with only minor modifications (blanking).



Figure 4. Liquid splitter test rig at Koch-Glitsch

MECHANICAL DESIGN

The key concerns for the mechanical design were safe installation and maintenance, speed of installation to minimise column downtime, and economy in manufacture.

The trays in the DW section were two-pass sieve trays designed to fit in either side of the DW. To speed the tray installation, FLEXILOCK® tray construction was used (Figure 5). These boltless panel joints allow a 30% saving in installation time compared to traditional bolted joints. The trays also had boxed downcomers at the DW end to simplify attachment to the DW.

The design of the DW (Figure 6) was the most important consideration. It was ~28 m tall and weighed ~4,000 kg. It had to be installed as quickly as practical, provide a good seal between the feed and product draw sides and support the trays. The design used new bolt-bars welded on both sides of the column. Cruciform sections

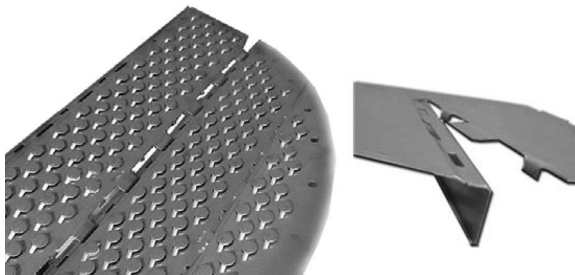


Figure 5. FLEXILOCK® tray construction



Figure 6. Trial assembly of DW at Koch-Glitsch

were welded between the bolt-bars to provide the required structural strength and supports for the trays. The wall itself consisted of panels bolted between the bolt-bars and the cruciform sections. It was sealed with PTFE gasket except at the feed and draw-off locations, which were seal, welded. Some panels were designed to be easily removable as manway sections to aid future maintenance by improving access through the column.

The design required several new nozzles to be installed for the bypass, feed and product draw-off plus new instrumentation. These were originally specified as set through; however, changing them to set on allowed them to be installed with minimum disruption to the work inside the column thus speeding the installation schedule.

INSTALLATION

The installation was performed safely and within schedule by Koch-Glitsch in 30 days during May 2005. Because the xylenes column was the only part of the plant shutdown, the installation was surrounded by live plant. Special precautions had to be taken during the hot work, particularly outside the column. Meticulous planning and superb cooperation between the ExxonMobil plant personnel and the Koch-Glitsch site crew were responsible for the successful installation.

OPERATION

The existing conventional energy balance control was retained with the temperature control point relocated to below the DW.

Test runs were carried out on the DWC during June–July 2005 proving its performance across the complete design range and beyond. No particular operability issues were discovered during the test run.

CONCLUSION

Lessons learned about the design of the liquid splitter chimney tray will allow more economical designs in the future. Very important lessons were learned about the design and installation of the DW. Changes to the construction and installation sequence are estimated to reduce the installation time by up to 50% with consequent savings in site costs and downtime.

ExxonMobil has classified this revamp as a complete success and within ExxonMobil, DWC technology is now fully endorsed and is being incorporated in additional projects. In the Fawley tower, energy savings of up to 53% have been achieved together with improvements in xylenes purity. Similar improvements in energy efficiency are expected in other applications. The Fawley project payback was very healthy. The Dividing Wall column technology has several potential future applications at the manufacturing sites and is expected to be a significant factor in ExxonMobil's continuing drive to reduce energy consumption at its refineries and chemical plants.

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Bernie Slade is a fractionation specialist with ExxonMobil Europe Ltd., based in Fawley UK. He provides a wide range of fractionation services to ExxonMobil's refineries and chemical plants in Europe and the Middle East, ranging from planning, design, detailed engineering, commissioning, start up, optimisation and troubleshooting.



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Dave Simpson has been with Koch-Glitsch since 1989 and has vast experience in the design of a wide range of column internals for mass transfer. He is responsible for a team of engineers providing process design and sales from the UK office.



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